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Energy Innovation Systems Indicator Report 2016

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Energy Innovation Systems

Indicator Report 2016

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Preface

This report collates a set of indicators, figures and tables for the energy innovation system in Denmark. Emphasis is on renewable energy and other technologies for moving towards sustainability. The purpose is to provide an overview of indicators available for illuminating dynamics and characteristics of energy innovation systems and to the extent possible offer figures of the developments in the individual indicators.

The report is an update of a report published in 2012. Graphs and numbers are updated with the most recent data available. The text is updated where needed in connection to the individual indicators as well as in the general remarks and conclusions. A limited number of new indicators and measurements are included. In addition, the accounts are in a few cases changed due to changes in data availability or in measurement methods.

The report is produced as part of the activities in "EIS – Strategic research alliance for Energy Innovation Systems and their dynamics – Denmark in global competition". EIS is funded by the Danish Council for Strategic Research (Innovation Fund Denmark) and by the involved research organisations.

The work is based on a number of existing statistics and analyses. Among the latter are a pilot report for Nordic Energy Technology Scoreboard (Klitkou et al., 2010), the eNERGIA project (Klitkou et al., 2008), the project "Patterns of need integration and co-operation in Nordic energy innovation systems" (Borup et al., 2008), a IPTS commissioned project on patents in the fields of wind energy, photovoltaics and concentrating solar power (Iversen and Patel, 2010), the EIS project (Borup et al., 2013a; 2013b; 2016) and analyses carried out in connection to the project "Framework conditions, innovation and growth opportunities in the energy area" (Borup et al., 2009; Tanner et al., 2009).

1 Introduction

Knowledge about the innovation systems with respect to new energy solutions and technologies is of central importance for understanding the dynamics of change in the energy sector and for discussion of opportunities for moving towards more climate-friendly and sustainable energy systems as well as for creating socio-economic development in the field, including creation of new businesses, work places, etc.

This is the topic that in general is addressed in the research activities of the “EIS – Strategic research alliance for Energy Innovation Systems and their dynamics – Denmark in global competition”. As part of this, the present report provides an overview of the available indicators of energy innovation systems and points out some of the limitations and strengths there currently are in these. Focus is on Denmark. Figures for other countries, primarily Nordic or European, are in some cases showed as well, offering a comparative perspective.

1.1 Why indicators?

Different dimensions of human activities and conditions have long been subjected to measurement. Measurements, for example, allow comparisons over time and between populations. Compiling measurements can be a useful means in taking stock and in determining the extent of change that may be due to different given factors. In terms of innovation, cross-country comparisons can be used to posit an empirical relation between e.g. knowledge accumulation and growth of output or productivity.

There are some initial caveats which should be noted at the outset of this report. A general one is that sometimes the zeal to measure can obscure or blind one to the purpose of the exercise in the first place. Indicators on the conditions and performance of low carbon energy technology are in many cases still taking shape. International data collection agencies such as the International Energy Agency (IEA), the Organisation of Economic Cooperation and Development (OECD), Eurostat, and others provide information about the established data collection standards and related guidelines which are documented along with limitations. This report presents data that in many cases are collected from such recognised authorities. In applying the data, however, one should remain critical of their use.

A second more specific caveat is that some activities and conditions lend themselves better to measurement than others (Verbeek et al., 2002). Even straightforward measures, such as greenhouse gas emissions, can pose difficulties. The measurement of technology and innovation activities is a far more challenging area that poses a set of general challenges both in terms of defining, collection and interpretation of data (OECD, 1992).

One indicator, or one number, does not in itself offer much insight. Only through comparison, or in other ways put in perspective and connected to other bits of knowledge, is true insight obtained. One of the reasons for gathering a number of different indicators together in one report is to establish an overview and a basis for insight that is otherwise rarely made available.

The target groups for the report are primarily policy and strategy makers, analysts, researchers, etc., dealing with issues of energy change and innovation either on national, societal or sector level, or on the level of an energy technology area as such. Hence, the indicators selected for the report contribute to overview and a general picture of the state of affairs, rather than insight in the details of energy innovation.

It is the intention that our analyses of indicators of energy innovation systems can contribute input to further discussions of developments of new and improved indicator standards. The focus of the report is on establishing overview and on identifying blind spots, methodological challenges, etc. To the extent possible, emphasis is on drawing on data sources that are as ‘official as possible’, preferably part of official statistics offered by recognized national or international institutions, up-dated annually, etc. This is however a trade-off, as many official statistics do not offer sufficient insight in energy innovation and are too general. Moreover, it is not always that the general, international databases have the best and most complete data. Therefore, a number of indicators are included in the report even though they are not officially established and not up-dated regularly.

1.2 Structure of report and indicator presentation

Chapter 2 firstly introduces the analysis perspective of innovation systems and suggests a row of indicators that are relevant for measuring energy innovation systems. Thereafter, the challenges of addressing renewable energy technologies and other low carbon technologies for sustainability are discussed and an initial description of the landscape of existing statistics and its current limitations is made.

Chapter 3 presents figures on a number of selected indicators. This includes comments and methodological remarks on individual indicators. The indicators are organised in three main categories:

1. Input indicators	The platform for the energy innovation system and public support and investments in it.
2. Throughput indicators	The working and dynamics of the energy innovation system – the activities and processes.
3. Output indicators	The performance of the energy innovation system – the resulting outcomes.

The chapter is structured accordingly with subsequent sections on input, throughput and output indicators.

Energy innovation systems are not machines. The categorisation in input, throughput, and output indicators shall not be taken as an suggestion of a mechanical understanding of energy innovation systems where a wanted output can be obtained 'just' by adjusting on the input side. Rather energy innovation and change are highly complex processes appearing through often long-lasting and multifaceted efforts. Linear development models are not adequate models of innovation and change in the energy systems. Spiral-like models with numerous circular processes and feedbacks offer a better explanation of reality. Change often to some degree grows out of the existing.

The geographical focus of the report is defined to Denmark and, to the extent comparable data are available, other Nordic countries, offering perspective and benchmark opportunities. We moreover explore the potential time-series for different data. Ideally, indicator data for every year ten, twenty, or more years back in time would be nice and preferred for the set of indicators in general. In many cases, this is however not available and shorter time periods as well as indicators that are infrequently updated are included as well.

The technological focus is on low-carbon technologies for sustainable energy systems, primarily renewable energy technologies like wind energy, bioenergy and solar energy, and energy efficiency technology. In some cases also other technologies are covered, e.g., conversion technologies like fuel cells and other areas of renewable technology like geothermal energy and wave energy that have until now been of smaller importance for Denmark.

2 Background – concepts and issues

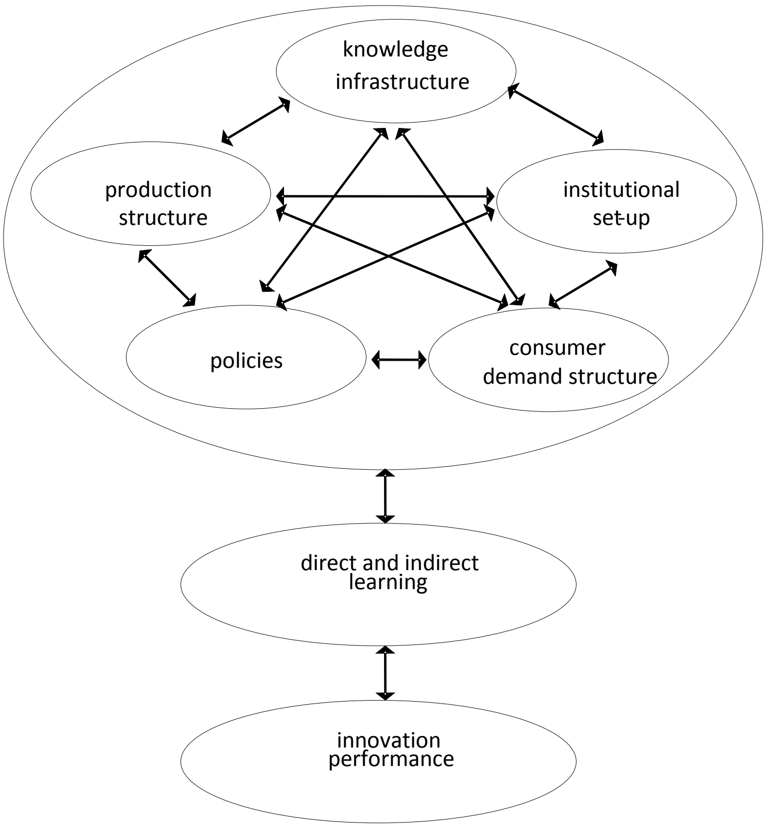
2.1 Innovation systems

Analyses of innovation systems have over that latest 20 years documented that patterns and conditions of innovation are not identical across the world but vary from country to country as well as between sectors and technology areas (Edquist, 1997; Edquist and Hommen, 2008; Hekkert et al., 2007; Lundvall, 1992; Malerba, 2002; Nelson, 1993).

Differences between the innovative performances of innovation systems can be ascribed to differences in the specific constitution of the learning and knowledge production, in the industry and market structures, and in the institutional set-up. This is illustrated in the figure below. The capability of change and innovation can usually not be explained by one factor alone, e.g. by science and research alone, by market forces alone, or by policies and institutions alone. On the contrary, the system character of innovation systems refers to the fact that development and innovation appear in complex interplay between numerous actors, e.g., companies, their customers and sub-suppliers, research and educational institutions, authorities, interest organisations, etc., and through a multitude of activities and interaction processes.

This makes it a challenge to establish a useful set of indicators of energy innovation systems. It points to that the quality of an innovation system cannot be measured by one, single measuring dimension only. Instead a combination of indicators must be employed.

Figure 1: Innovation systems and their innovation performance.



Source: Gregersen and Johnson (1997)

Central constituents of innovation systems are the set of actors involved, their networks, the institutions, and the infrastructure developed including e.g. communication and knowledge systems, energy and transportation systems, market structures, standards and certification systems. In its' most general sense, an innovation system can be defined as "the elements and relationships, which interact in the production, diffusion and use of new and economically useful knowledge" (Lundvall, 1992, p. 12). Knowledge is hence central, but only in the broad sense that includes both informal knowledge and formalised knowledge. By employing the term learning, innovation system analyses ensure this and address knowledge and competence build-up broadly, ranging from market-based learning, learning-by-using and learning-by-doing over entrepreneurial experimentation and industrial product development, to formalised knowledge production, research and educations at universities.

In line with Lundvall's definition of innovation system, "innovation" can be seen as an original contribution to the stock of knowledge in the economy (Verspagen, 1994). Innovation process hence encompasses a series of scientific, technological, organisational, financial and commercial activities, whose boundaries are not necessary sharp. The underlying activities and the overall process are seldom homogeneous and ideal, but often pragmatic and particular to a given situation.

Maturity and functions in establishment of new technology areas

The dynamics of innovation systems differ between mature areas where industrial networks and market applications are well developed, and immature areas where the networks are scattered and market application has not, or only to a small extent, been reached (Foxon et al., 2005; Jacobsson and Bergek, 2004). In mature areas, industrial companies, consumers, markets, and industrial interest organisations are usually central and the number of actors is high. In immature areas other types of actors, e.g., policy makers, public agencies, research communities, environmental interest organisations, or public movements can often be more central and the number of actors will typically be smaller. The differences between mature and immature areas are a challenge for establishment of a set of indicators of energy innovation systems, not only in sense of measuring whether it is mature or not, but also in the sense of being able to detect dynamics and characteristics in both kinds of areas. Change from an immature to a mature situation is moreover a complex and usually long-lasting process. This is a further measuring challenge.

Table 1: Functions of innovation systems for establishing new technologies for sustainability (Hekkert and Negro, 2009) and examples of indicators.

Functions:	Examples of indicators:
Entrepreneurial activities and experimentation	- Experimental application projects - New product introductions - New businesses
Knowledge development (learning)	- Scientific publications - Technology application (learning-by-using) - R&D funding - Patents
Knowledge exchange in networks	- Collaboration patterns - Demonstration projects - Network participation - Conferences and debate meetings - Interest organisations (industrial, environmental, etc.)
Market formation	- Market application - Public market support - Trade and exports - Standards and certifications
Mobilization of resources	- R&D funding - Investments - Personnel - R&D / other
Guidance of the search – shared visions	- Policy action plans - Shared strategies and roadmaps - Debate activities
Legitimacy	- Public opinions on energy technologies and systems - Regulatory acceptance and integration

The difference between mature and immature areas is addressed in a number of analyses of technology-specific innovation systems (Hekkert and Negro, 2009; Jacobsson and Bergek, 2004). It is identified that in order for new technologies to move towards a more well-established and mature situation, a number of activities, or 'functions' in the innovation system are typically important. The functions are shown in Table 1 together with examples of indicators that are relevant in connection to the individual functions.

The functions are overlapping and should not be understood as mechanical or functionalistic building blocks. Moreover, the functions are activities considered on a relatively general level. The specific interaction patterns and development dynamics within and between the different functions can take on many shapes. The point is, however, that the functions generally appear in connection with development of a new technology area, at least in cases where the technology becomes successful and obtains widespread application; and maybe, ultimately, changes the existing technology regimes in a sector. This point is highly relevant when considering energy innovation and changes towards more sustainable energy systems.

The conceptual framework established by the OECD in the early 1990s for collecting and interpreting data on technological innovation and R&D provides a useful point of reference for this exercise. The first edition of the 'Oslo Manual' on the measurement of scientific and technological activities defined innovation rather narrowly in terms of new products and processes and significant technological changes in product and processes (OECD, 1992). However, this was not sufficient for understanding innovation systems. The OECD's 'Frascati Manual' for analysing R&D noted that innovation activities can only really be measured indirectly, using input and output indicators (OECD, 1994). The Frascati manual listed the following six activities for innovative activities (OECD, 1994, p. 20).

- Tooling-up and industrial engineering
- Manufacturing start-up and pre-production development
- Marketing for new products
- Acquisition of disembodied technology
- Acquisition of embodied technology
- Design.

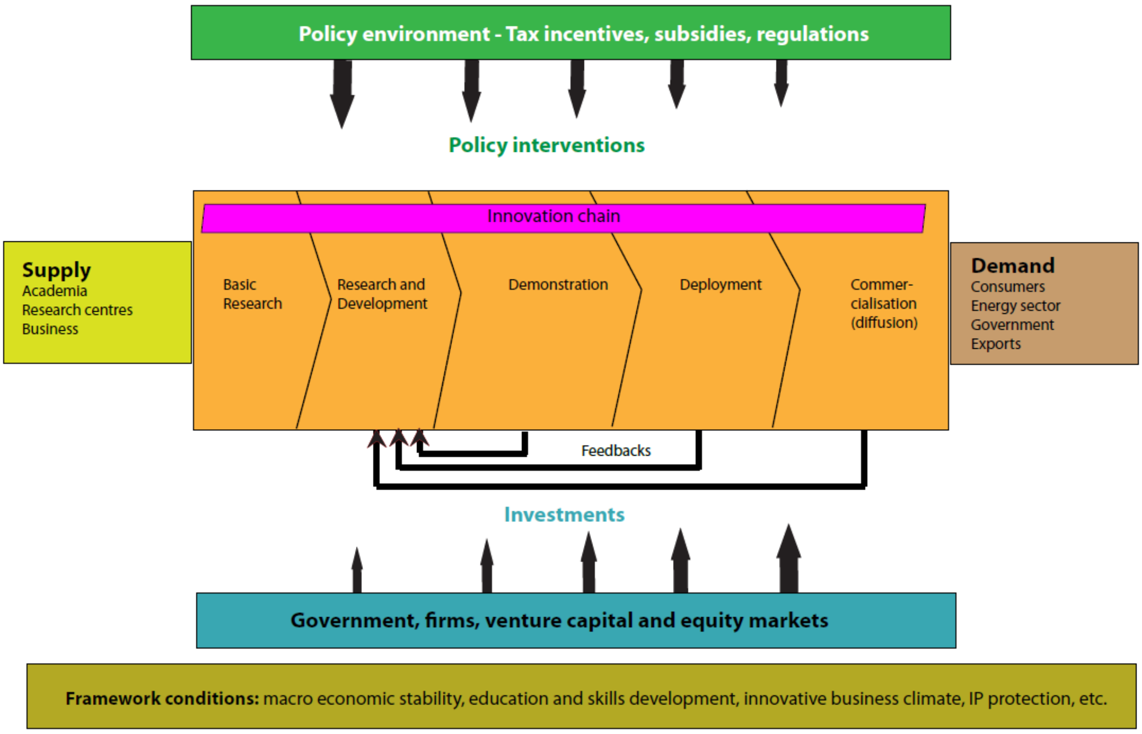
These can be understood as important build-up activities in the perspective of an individual company, but they are also not sufficient for understanding innovation systems.

Since the beginning of the 1990s the Oslo Manual has been developed further. In 2005, with the third edition the innovation measurement framework was expanded in three ways: (1) the role of linkages between firms and institutions was emphasised; (2) innovation in less R&D intensive industries was more recognised; and (3) in the definition of innovation was included also organisational innovation and market innovation (OECD, 2005, p. 6f.). These changes have contributed to a shift from a R&D dominated view on innovation. Organisational innovation is important for understanding learning capabilities in firms and marketing innovations are important to understand interaction with customers and demand-driven innovation processes.

The *analysis of linkages* is necessary to capture the diffusion of knowledge in technological innovation systems. For analysing linkages the Oslo Manual (2005) proposes following types of linkages: (1) *open information sources* which do not require the purchase of IPR, such as R&D journals, patents, standards, professional conferences, public regulations etc., (2) *acquisition of knowledge and technology* either embodied in capital goods (machinery, equipment or software) or acquisition of external knowledge (licenses, designs, trademarks etc.) or services provided by commercial or public sources including designing activities, testing and engineering services, (3) *innovation cooperation* with other firms or public research organisations.

The following figure lays out the schematic dimensions of a generic innovation process in the context of a set of external factors that will affect innovative activities (IEA, 2008). These external or structural elements include policy factors as well as underlying conditions such as access to a skilled labour force. It can be used for distinguishing between different types of support measures, the importance of the policy environment and other framework conditions and feedback loops from demand back to the supply side.

Figure 2: Innovation system and generic model of innovation processes in the context of external factors, applied to the energy field.



Source: adapted and modified from Grubb, 2004 and Foxon, 2003 and ETP 2008

We distinguish between input, output and throughput indicators following Grupp and Schwitalla's taxonomy (Grupp and Schwitalla, 1989). *Input indicators* or *resource indicators* include a diverse set of measures for the allocation of human and other resources to the innovation process. Common input measures include R&D outlays and R&D personnel. They are among the most standardised and used measures of innovative activity. These measures however generally do not pick up input to other innovation activities that are not directly associated to R&D. Moreover, collaborative R&D efforts or R&D activities of international industry players across national borders are difficult to capture by national data.

Output indicators according to Grupp and Schwitalla attempt to capture the economic effects of the innovative activity in question. However, measuring output is more challenging. One challenge is that economic effects are not the only interesting products of innovation processes. There are others such as a learning effect which will only indirectly contribute to the economic bottom-line; or changes in energy systems and in the opportunities for energy production or energy consumption that can imply changes also concerning climate impacts. A second challenge is that it is not always easy to distinguish the economic effects of the innovative activity from that of other activities taking place in parallel. Changes at the energy system level, such as the energy mix of a country, the access to renewable energy resources or the declining access to fossil energy sources, can have a considerable impact on the future possibilities and direction of the development of the innovation system.

In addition to the standard measures of input and output indicators, a third class of measure is so-called *by-put* or *throughput* indicators (Grupp and Schwitalla, 1989). Throughput indicators are measures that attempt to capture the intermediate products of the innovation process, e.g. those often emanating from formal R&D processes, but also many other processes which are not related to R&D can be measured as throughput indicators. Throughput indicators are for example patents, bibliometric, and citation statistics. Table 2 provides a presentation of these categories of measurement in terms of their function during the innovation process.

Table 2: Functions of technological innovation systems and possible linkages to input, throughput and output indicators

Functions	*Input indicators*	*Throughput indicators*	*Output indicators*
Entrepreneurial activities and experimentation		Experimental application projects	New product introductions New businesses
Knowledge development (learning)	R&D funding and projects	Scientific publications Patents Citations User-driven innovation processes Demonstration and trial projects	Technology application (learning-by-using)
Knowledge exchange in networks	R&D networks	Demonstration projects Collaboration patterns Cluster participation Interest organisations Conferences	
Market formation	Public market support	Standards and certifications	Market application Market shares Trade and exports Environmental impacts
Mobilization of resources	Public R&D funding Business R&D Investments R&D personnel R&D programmes		Employment
Guidance of the search – shared visions	Policy action plans Shared strategies and roadmaps	Debate - meetings/media Strategy networks Scenarios and foresight projects	Industrial strategies
Legitimacy	Regulatory acceptance and integration	Public opinions on energy technologies and systems	

2.2 Low carbon technologies

The nature of low carbon energy technologies pose a number of particular measurement challenges in addition to the general issues mentioned above.[1] One challenge is how to measure emerging technologies (IEA, 2006). A number of low carbon energy technologies which are still not fully mature are interesting to track. An additional challenge is that the set of technologies in question vary not only in their technical maturity but also in the maturity of their intermediate and end markets, the industrial networks, etc. This raises the question of how to account for the differences between and within the different types of renewable energy technologies.

This has clear implications for the degree to which input, through-put and output measures are applicable for the individual technologies. We can distinguish between three groups of technologies, but there are overlaps and competition between these groups of technologies (IEA, 2006):

[1] See Smith (2008) for a discussion.

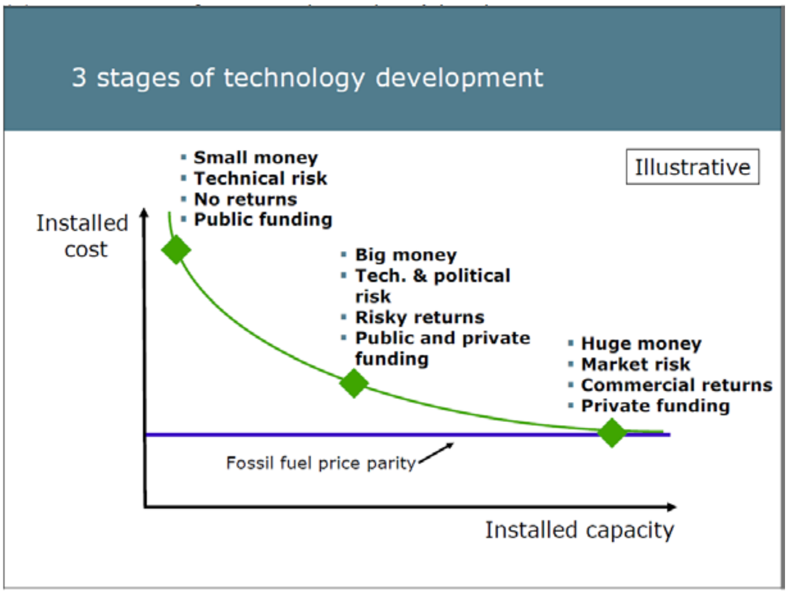
(i) technologies which have already reached a considerable degree of maturity, such as hydropower, biomass combustion, onshore wind and geothermal energy;
(ii) technologies which are undergoing rapid development such as solar energy, offshore wind power and modern forms of bio-energy;
(iii) technologies which are presently in developmental stages such as ocean energy, concentrating solar power, improved geothermal, CO_2 capture, storage, and integrated bio-energy systems.

A further set of challenges is associated with the scale of the technologies. A major aspect here is that the technological innovation systems for "low carbon" technologies can involve the deployment of large-scale experimental sites to demonstrate and test different modes of the technology (e.g. carbon capture and storage or offshore wind). These deployment/demonstration sites can require large allocations of public and private resources without providing immediately profitable output. Standardised statistics need to be developed to capture this peculiarity. Another aspect to consider is associated with scale and the involvement of the public sector. Energy systems tend to be partly or fully public owned, at least in Northern Europe.

The technologies are not necessarily stand-alone technologies but may involve significant changes in different parts of existing value chains. For example biofuels require change or complementary developments in engine manufacturing as well as fuel distribution. A first implication that is caused by the systemic of the technologies is that cooperation is likely to be important during the development and deployment of the technologies. Public-private cooperation is one way to overcome resistance and path dependency in the energy sector. Strategic oriented energy companies are often investing in R&D and in many cases do so in close collaboration with research organisations. Measures of cooperation are therefore important, but difficult to get. The innovativeness of the public sector and public procurement of new energy technologies can facilitate the successful development of low-carbon energy technological innovation systems and they should be measured to improve our understanding.

A second implication is that the deployment of the technologies may face different degrees of resistance from established and competing systems based on other (e.g. carbon-based) energy sources. A degree of coordination and guidance of the search is necessary in order to overcome such resistance. This implies coordination-costs to facilitate deployment of the emerging technological systems. Figure 3 from Grubb (2004) illustrates that these technologies face a fundamental challenge in competition with the established and pervasive fossil fuel paradigm. It suggests first that an overall measure for the dissemination of renewable technologies will ultimately be their ability to compete with the costs of energy generation based on fossil fuels. Switching costs are very high and build barriers for further development and deployment of emerging low carbon energy technologies.

Figure 3: Main stages of technology development.



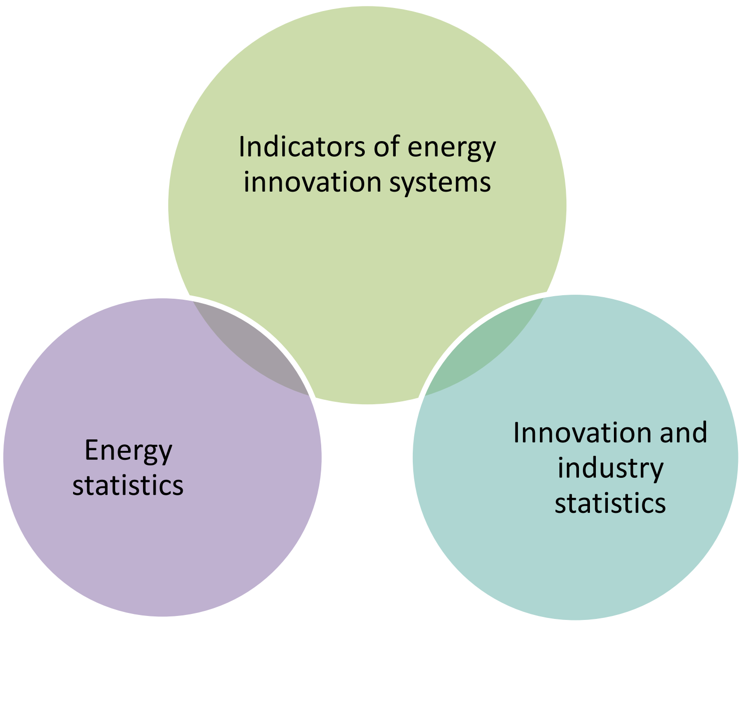
Source: Grubb (2004)

Another feature is that technologies related to fossil fuels do not stand still. Innovation also continues to improve the efficiency of fossil fuels. Following Grubb, this suggests the use of data on R&D budget for fossil fuels as a measure of *carbon-lock-in*, i.e. comparison of expenditures on the different groups of technologies in IEA's RD&D budget indicator – energy efficiency, fossil fuels, renewables and nuclear technologies, hydrogen and fuel cells, other power and storage technologies, total other technologies or research (Grubb, 2004). See also Kaloudis & Pedersen (Kaloudis and Pedersen, 2008) on the use of R&D for a composite of all energy production technologies. In this context it is useful to appreciate that different low-carbon energy technologies may represent incremental, disruptive, or radical modes of innovation (Smith, 2008). Different technologies have different development rates, which in turn implies different degrees of public funding to overcome coordination costs, technological and market uncertainty, and rigidities in existing structures.

2.3 Between energy systems and innovation – existing statistics

In the pursuit of a useful set of indicators of energy innovation systems, two existing fields of statistics constitute main pillars of references where much can be drawn from: 1) Energy statistics; and 2) Industry and innovation statistics. Energy statistics is well-established in many countries. It monitors the energy systems and their development over the years. Apart from general figures on energy consumption and energy production, the national energy statistics in some countries also include data on amongst other things energy sources, climate emissions, and energy production by different energy technologies; renewables as well as others. On international level, the national statistics are gathered by among others Eurostat and the International Energy Agency (IEA). Well-established R&D statistics are also available for Denmark as well as internationally where the International Energy Agency collects data from a large number of countries on public R&D support within different areas of energy technology.

Figure 4: Energy statistics and innovation and industry statistics as important sources and reference points for establishment of a set of energy innovation system indicators.



Industrial innovation statistics have been developed in the latest decade both on national, international and European level. Though the schemes of innovation statistics have become more well-established, they still tend to change in contents from one time they are run to another. A degree of harmonized approach among the European countries is obtained, enabling comparison between countries and common publishing in the Communities Innovation Surveys (Eurostat) and the European Innovation Scoreboards and, in the most recent years, the Innovation Union Scoreboards (EC DG Enterprise and Industry). The innovation statistics can provide information on e.g. enterprises' R&D investments, frequencies of new product introductions, etc.

In the background behind the innovation statistics are the long well-established statistics fields of trade and industry statistics. Through the trade and industry statistics, the domestic and international trade of products can be illuminated.

What limits the use of the statistics on innovation, trade and industry for our purpose is that they usually do not address the energy sector specifically and that they only to a limited extent cover energy technology products as individual product categories. For example, many renewable energy technologies do not have their own product categories in these statistics. Moreover, the indicators included in the schemes of industry and innovation statistics are seldom about innovation <u>systems</u> as such, but primarily about innovation in the sense of product introductions and business development. The data is gathered on the level of individual companies, i.e. the innovation statistics do usually not provide insight in innovation considered on a system level or on societal level.

Some of the other major gaps in the existing statistics and indicator schemes are amongst other things a lack of indicators of other types of knowledge production than formalised, scientific knowledge (e.g. industrial competence build-up and know-how, learning-by-doing and learning in interaction between other types of actors than research institutions). Concerning application-based learning (learning-by-using), though, there is one important indicator established, namely the indicators of application of different energy production technologies in the domestic energy systems. The more detailed characteristics of user- and demand-driven innovation are however less well reflected in the existing statistics. Another major gap in the existing statistics is developments in actor landscapes, including industrial supply chains, broader innovation networks and actor alliances in different areas of energy technology.

3 Indicators and methodological considerations

3.1 Input measures

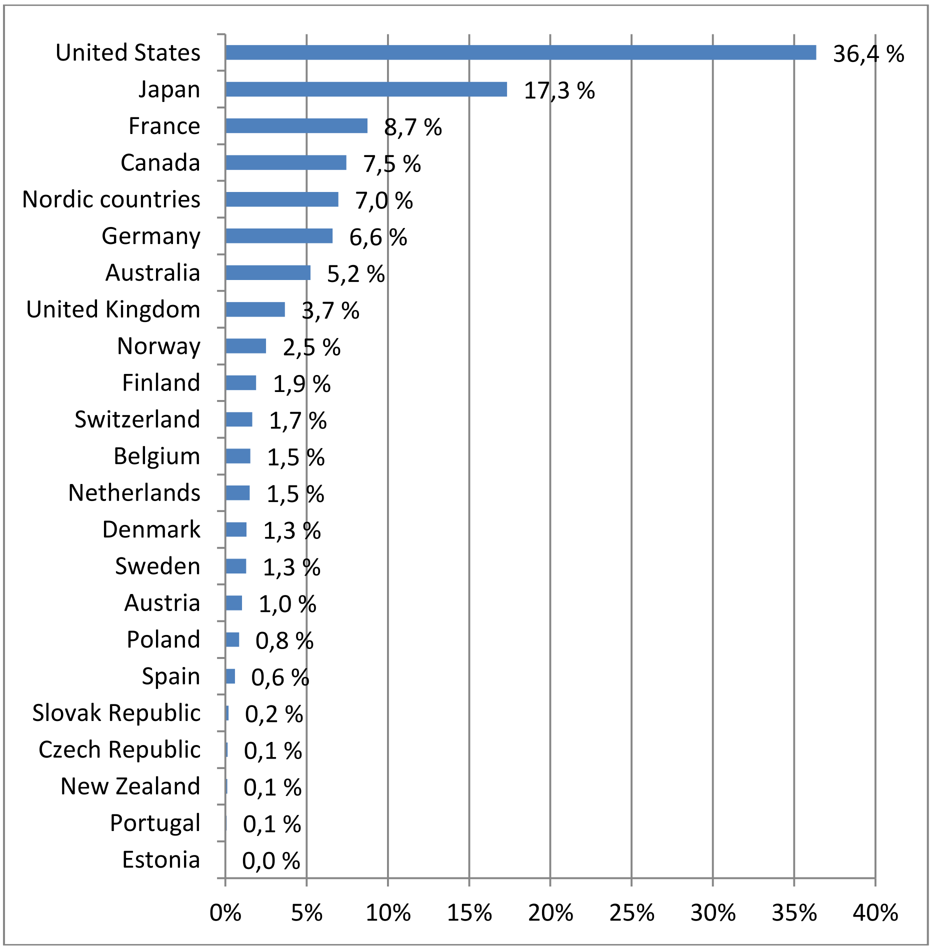
3.1.1 Public RD&D investments

The report will feature a set of technology specific input measures are: expenditure on research, development and demonstration activities (RD&D expenditure) decomposed to identify the demonstration dimension.

The IEA RD&D statistics are used as input measures. The IEA energy R&D statistics are collected from government R&D funders and use a scientific/technical nomenclature and are publicly accessible. The budgets are reported on a level of detail that makes it possible to distinguish between the energy technologies used in this report. The IEA database also covers 20 EU Member States. All Nordic countries, with the exception of Iceland are included in the database. The database allows for an analysis of public energy RD&D investments over a long time period. In this report values from mid-1970 to the latest available data, 2013 has been covered. The tables give data for every second year.

On top of research and development budgets the IEA database covers *demonstration budgets*. Demonstration projects are large “test” projects which are not yet operating on a commercial scale. Demonstration budgets are however scarcely reported in the database. As has been explained elsewhere most IEA member countries do not provide data on funds towards demonstration, or do not report them separately (Wiesenthal et al., 2009). Demonstration budgets are typically available since 2004 and for the Nordic countries some data is available, but the systematic reporting and collecting of demonstration budgets need to be improved further.

Figure 5: Public energy RD&D budgets as percentage share of estimated total IEA budget in 2013. Source: IEA



Note: Seven IEA member countries have not reported: Greece, Hungary, Ireland, Italy, Korea, Luxembourg, and Turkey.

An indicator for the need of international RD&D energy cooperation has been constructed by calculating the countries' share of public energy RD&D budgets of the overall IEA spending. The Nordic countries budgets for energy RD&D combined constitute about 7.0% of the total IEA budget in 2013, while Japan and USA give combined about 54% of the total IEA funding (see Figure 5). A conclusion from this is that international research cooperation is essential, especially for small countries in order to increase their access to a larger pool of resources and strategic knowledge, generate synergies and avoid duplication.

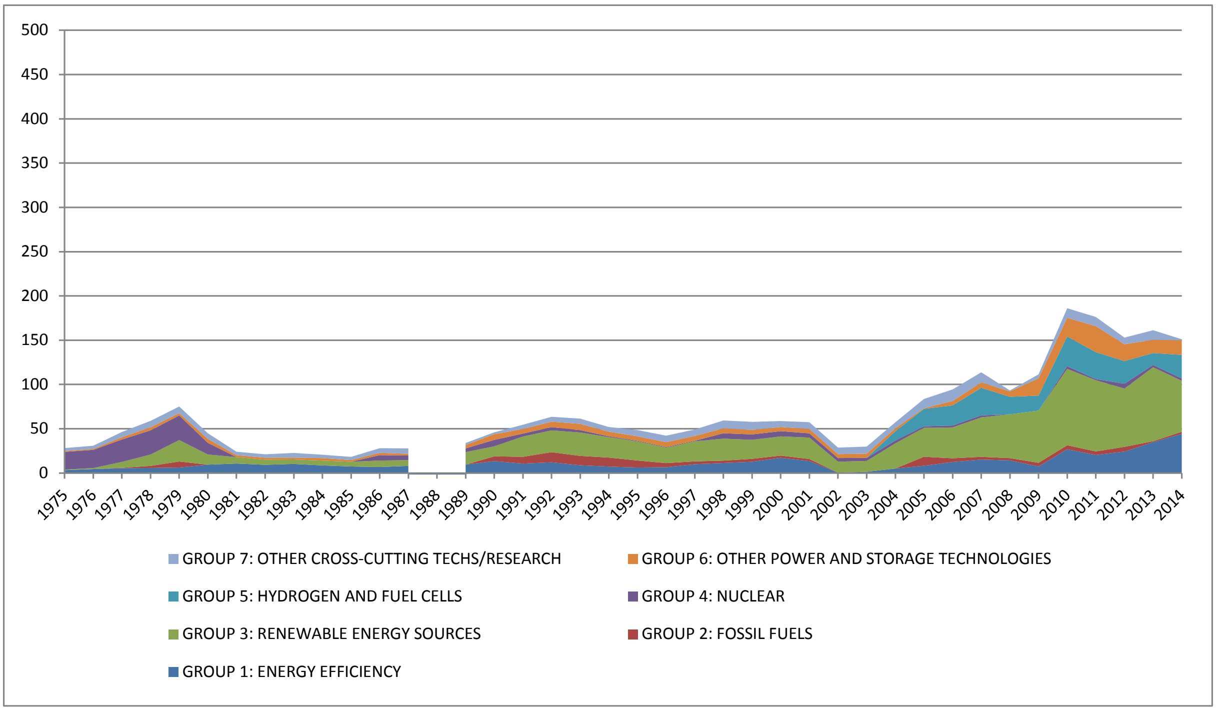
In the next figures the trends in RD&D budget distribution over the main groups are illustrated, as classified by the IEA:

Table 3: Classification of main energy RD&D groups in IEA RD&D statistics.

I.	Energy Efficiency
II.	Fossil fuels
III.	Renewable energy sources
IV.	Nuclear fission and fusion
V.	Hydrogen and fuel cells
VI.	Other power and storage technologies
VII.	Other cross-cutting technologies or research

For Denmark, Figure 6 shows dominant position of public funding of RD&D on renewable energy sources, hydrogen and fuel cells and other cross-cutting technologies, while funding of RD&D on fossil fuels and nuclear fission and fusion is marginal. For Norway, the picture is different (see Figure 7). Here has dominated RD&D on fossil fuels and to a lesser extent renewable energy. For Sweden and Finland, the focus was on energy efficiency and renewable energy sources (Figure 8 and Figure 9).

Figure 6: Denmark, Mill. €. RD&D budgets for main groups, 1975-2014. Source: IEA



Note: For 1988 are no values available.

Figure 7: Norway, Mill. €. RD&D budgets for main groups, 1975-2014. Source: IEA

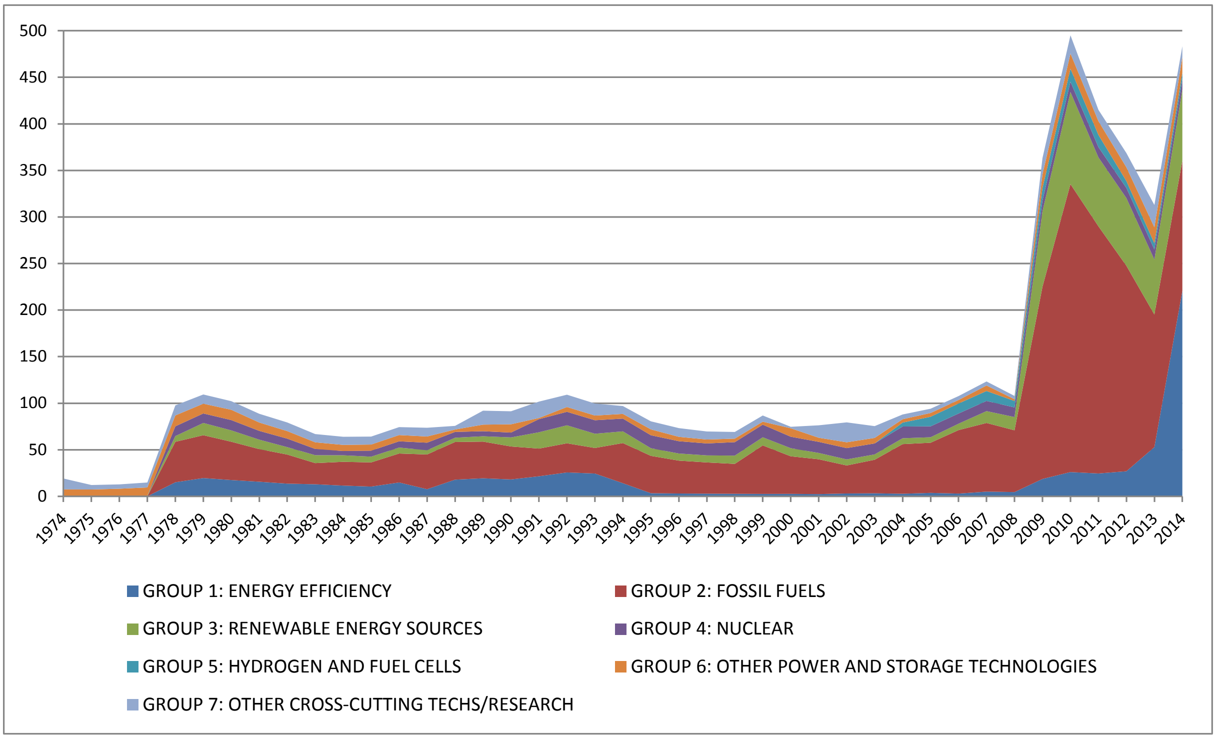


Figure 8: Sweden, Mill. €. RD&D budgets for main groups, 1975-2014. Source: IEA

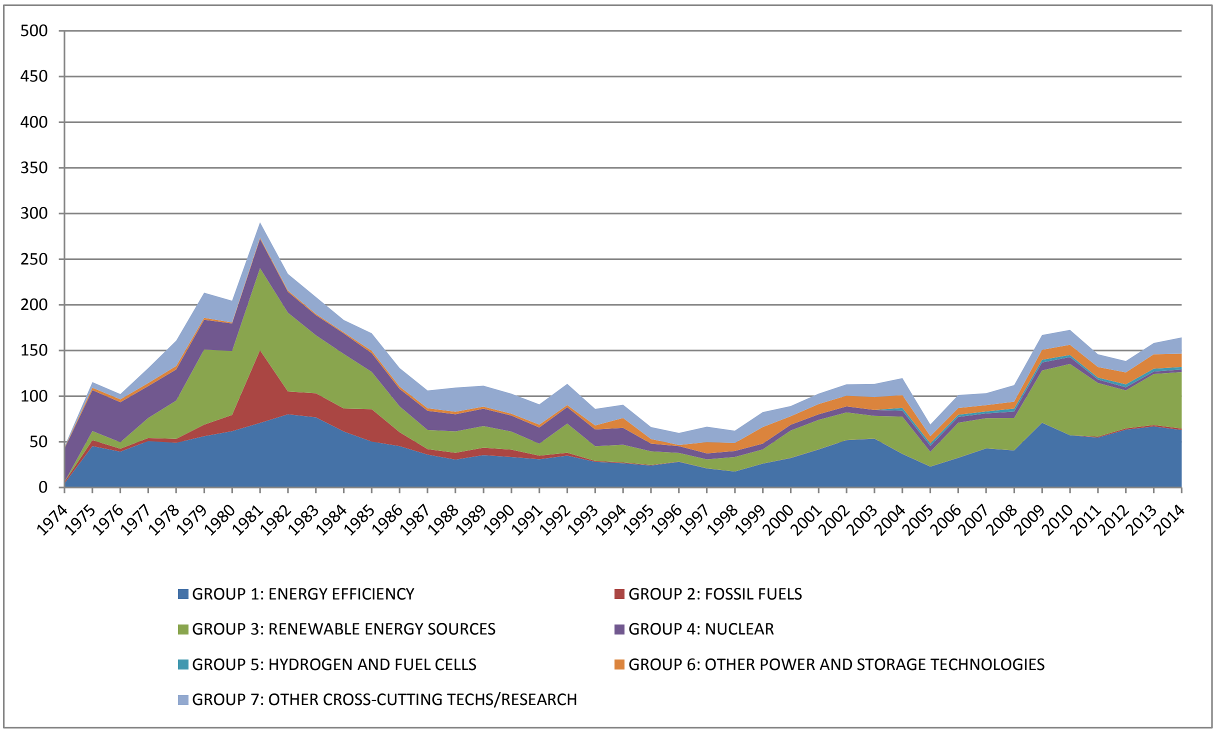
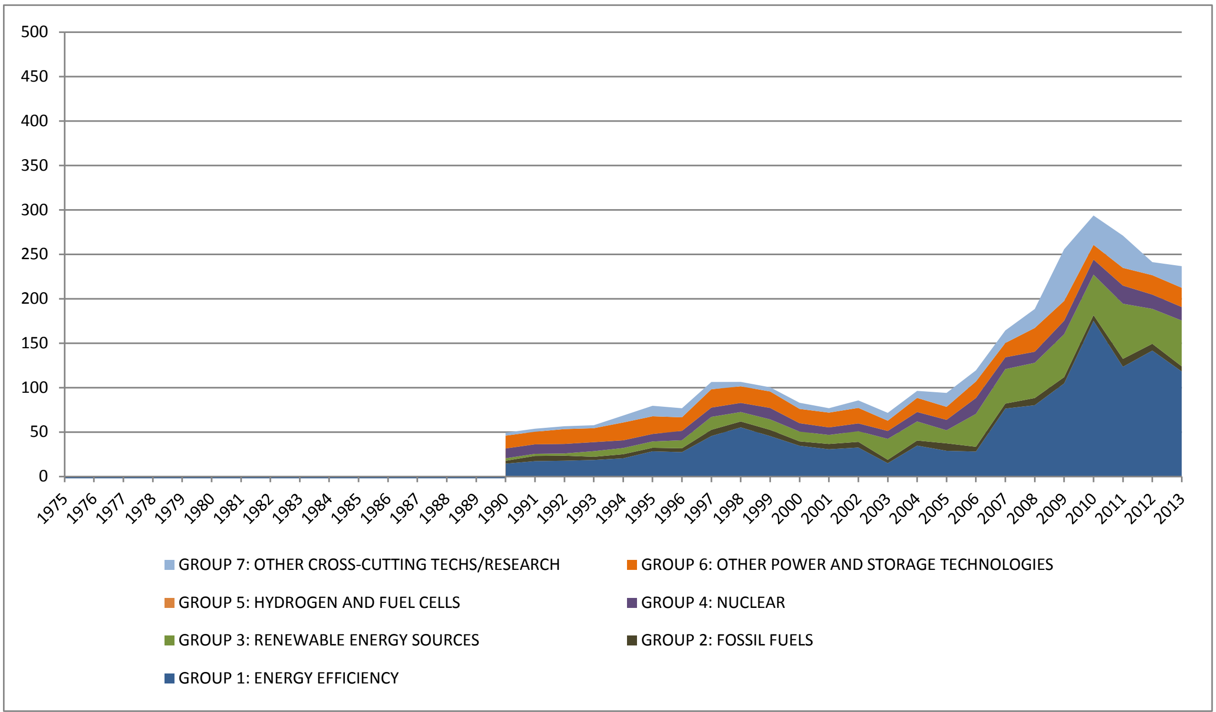


Figure 9: Finland, Mill. €. RD&D budgets for main groups, 1990-2013. Source: IEA



Note: Values for 1975 to 1989 are not available.

The advantage of the IEA database is that it provides public RD&D budgets by energy technologies over a relatively long time period. This means that it is possible to compare trends in budget distributions by renewable energy sources, energy efficiency areas, power and storage technologies and carbon capture and storage. The figures presented below illustrate budget developments, where some of the data is available since mid 1970's, where available upto 2010 for the energy technologies relevant for this project. The technologies are classified by the IEA in the following way:

Table 4: Classification of (selected) energy relevant sectors in IEA RD&D statistics.

I.1 Energy efficiency - Industry
I.2 Energy efficiency: Residential & commercial buildings, appliances and equipment
I.3 Transport
I.4 Other energy efficiency
II.3 CO_2 Capture and Storage
III.1 Solar Energy
III.2 Wind Energy
III.3 Ocean Energy
III.4 Biofuels (incl. liquids, solids and biogases)
III.5 Geothermal Energy
V.1 Hydrogen
V.2 Fuel cells
VI.1 Electric power conversion
VI.2 Electricity transmission and distribution
VI.3 Energy storage

For Denmark, the focus over the years was on wind energy and biofuels, while over the last years also fuel cell technology has gained substantial attention in public RD&D budgets. Energy efficiency in buildings and in transport has been addressed increasingly over the last years.

Figure 10: Denmark, Distribution of low carbon energy RD&D budgets, Mill €. 1975-2014, Source: IEA

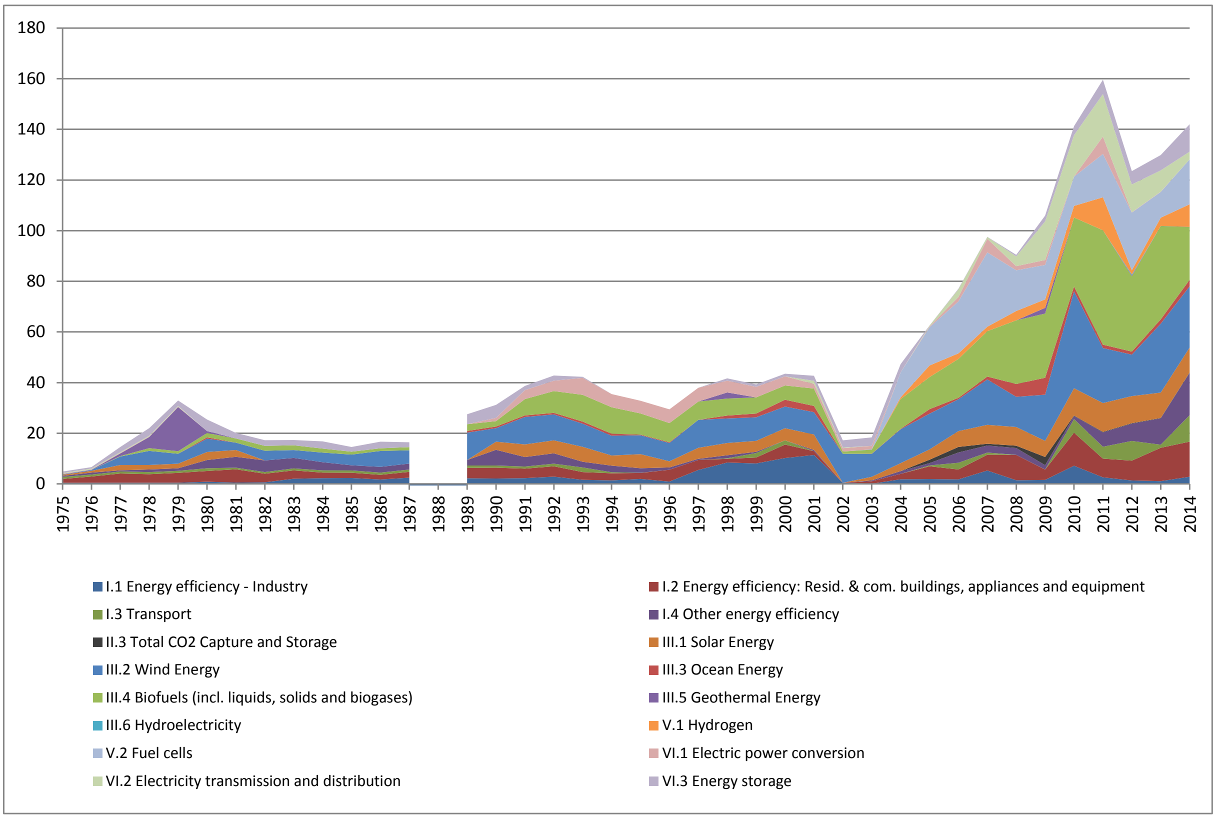
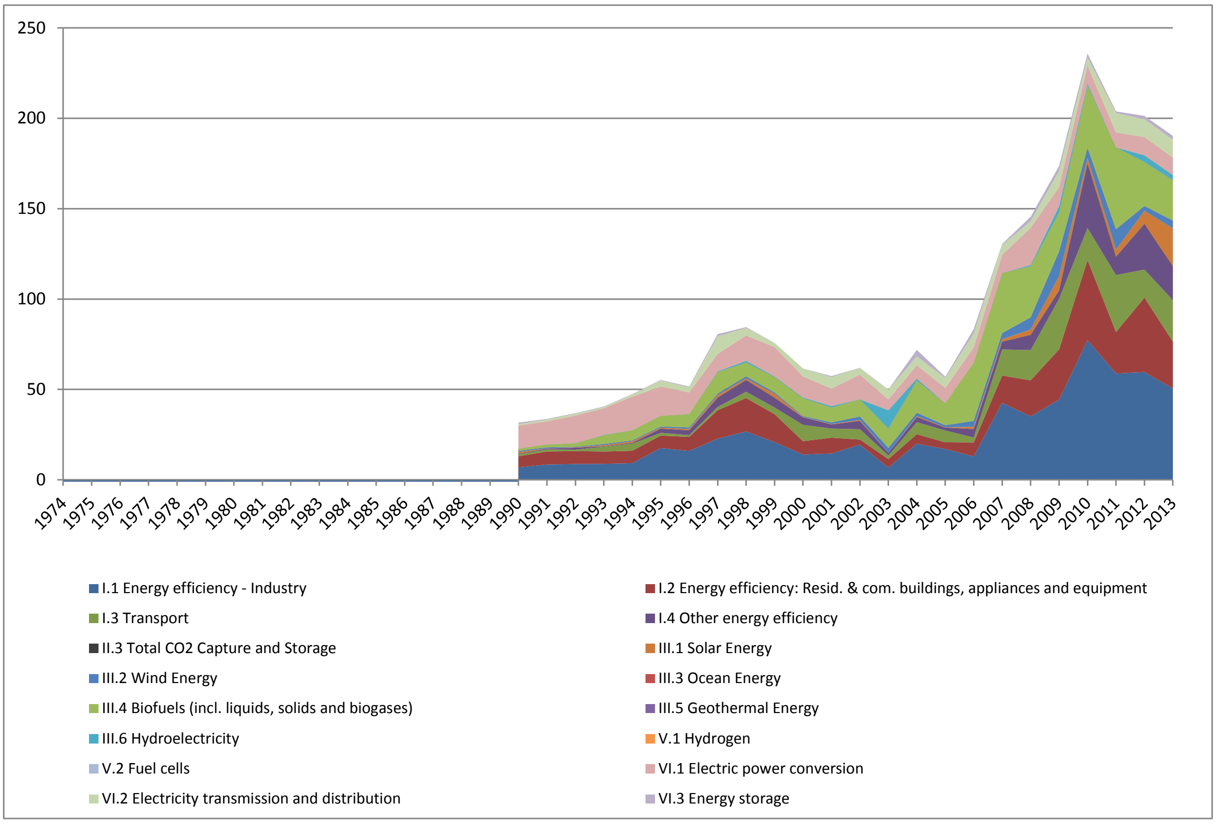
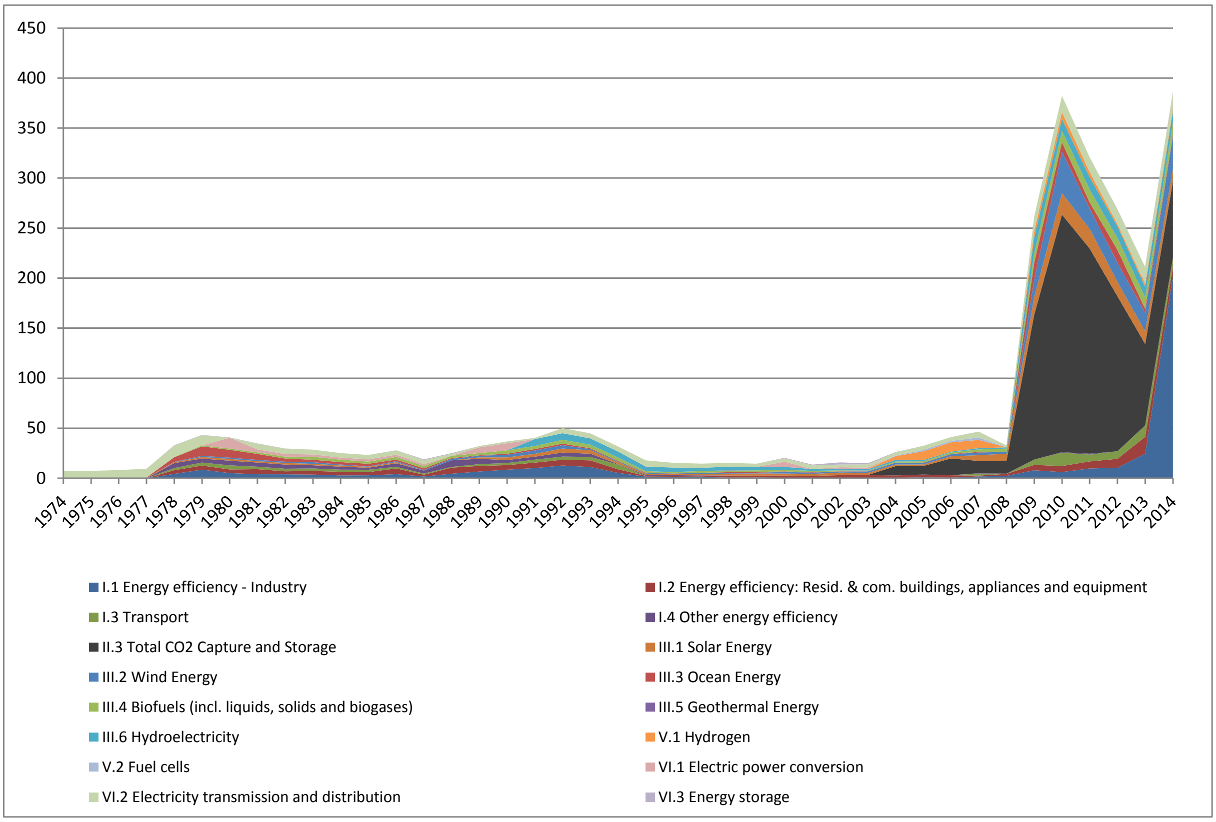


Figure 11: Finland, Distribution of low carbon energy RD&D budgets, Mill €, 1975-2013. Source: IEA



The public RD&D budgets of Finland have a focus on energy efficiency, as well as in industry, in residential and commercial buildings, appliances and equipment, and in transport. However, over the last years this has been diminished somehow. In the field of renewable energy sources stand biofuel highest on the agenda. In 2013, solar energy came higher on the priority list.

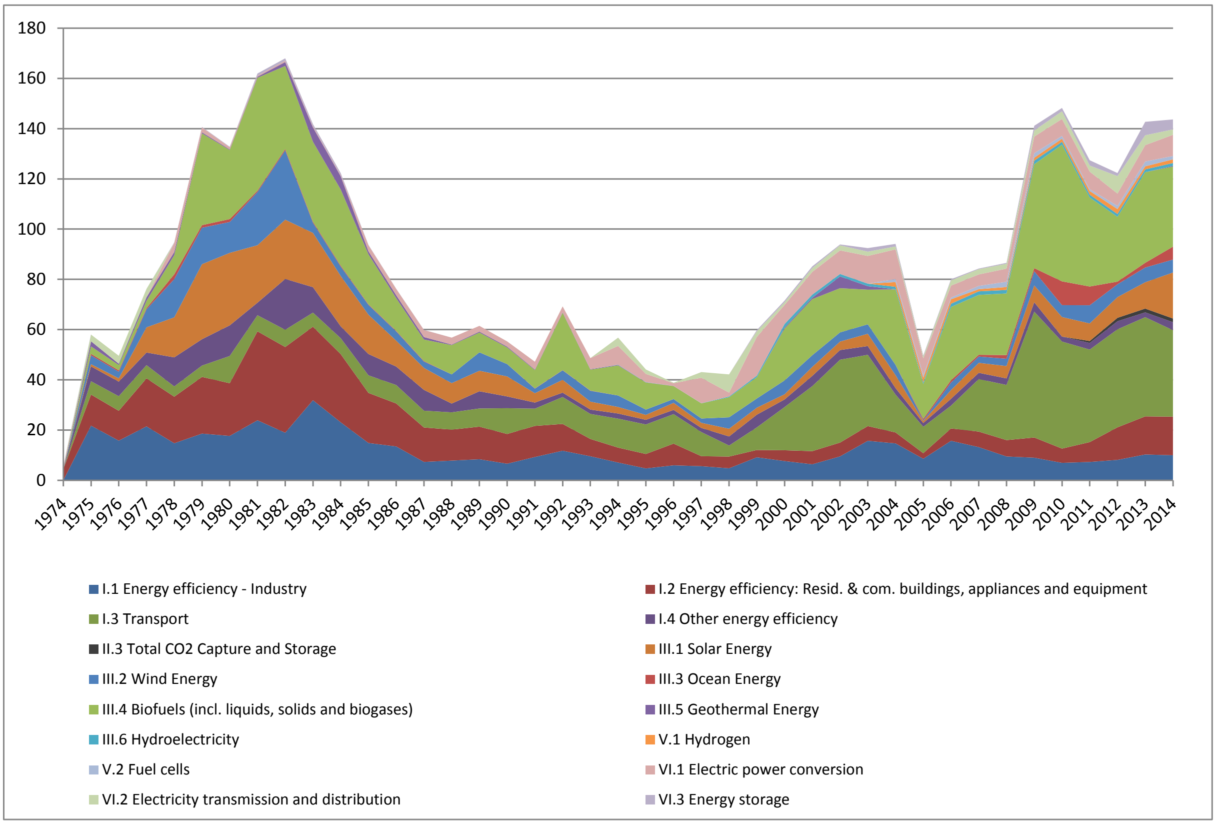
Figure 12: Norway, Distribution of low carbon energy RD&D budgets, Mill €, 1975-2014. Source: IEA



For Norway can be found long traditions for funding of energy efficiency in industry, but this field received much less attention from the midle of the 1990s until 2008. In 2014, this field received most of the funding, also much more than carbon capture and storage (CCS). CCS received very much funding since 2004, but this has been reduced over the last years. In the field of renewable energy solar energy, wind energy and biofuels are prioritised. RD&D on Electricity transmission and distribution, and hydrogen have been prioritised as well.

Swedish public funding of RD&D has prioritised energy efficiency as well as in industry, in residential and commercial buildings, appliances and equipment, and especially in transport. In the field of renewable energy biofuels were prioritised.

Figure 13: Sweden, Distribution of low carbon energy RD&D budgets, Mill €. 1975-2014. Source: IEA

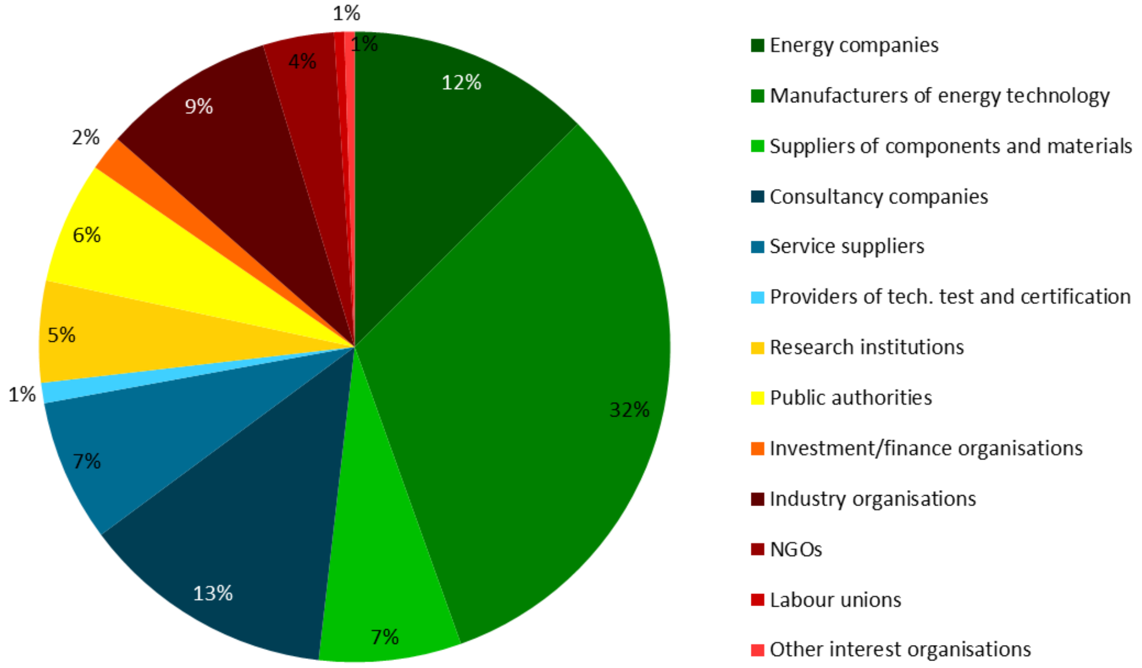


3.1.2 Actors

The energy innovation system includes many different actors. It is difficult, however, to provide a complete and 100% exact picture of the actor landscape. One reason is that it is a challenge to identify all relevant actors and no authorized and complete database of actors exists. Another reason is that the borders of the energy innovation system to some extent are fuzzy, not only because some actors disappear over time and new actors appear, but also because some actors are only 'part time' involved in field, influencing energy innovation in parts of their activities, but not in all their activities. This can for example be sub-suppliers of central, specialized components of energy technologies (e.g. suppliers of solar cell materials for solar cells systems, or suppliers of components for wind turbines) who sell, say, 20% of their production to the energy technology industry while the rest is sold to other industries. It can also be e.g. finance and investment organisations that in part of their activities have energy investments as a focus area, or policy makers that establish central new, regulations that influence conditions for energy innovation. Hence, there will always be a degree of uncertainty about which actors are included in the energy innovation system, and which are not.

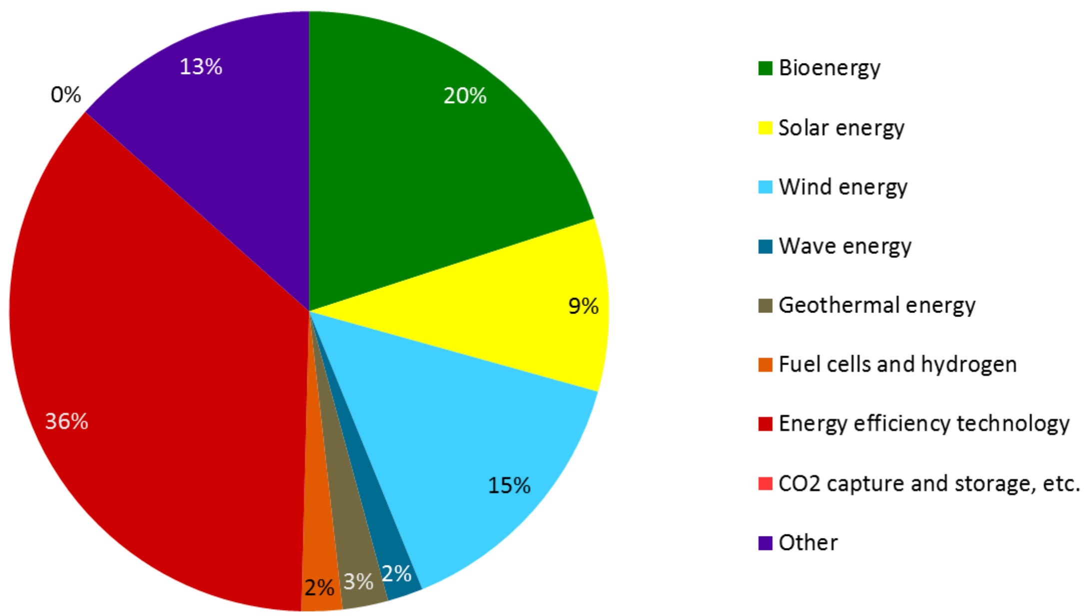
In case of the Danish energy innovation system, the EIS surveys of innovation activities and interaction patterns (Borup et al., 2013 and 2016) can provide an overview picture of the landscape of actors in relation to low-carbon technologies. According to these analyses, the energy innovation system has been growing in the recent years and now has in the order of 1800 actors (compared to 1500 in 2011; energy consumers, media organisations, and politicians are not covered). The analysis indicates a distribution of types of actors as shown in Figure 14. Most of the actors identified (70-75%) are companies of different kinds. More than half of the actors are suppliers of energy technologies or of components or services in connection to energy technology. This includes consultancy companies. Energy companies (including energy-net operators) constitute 12% of the actors. The remaining 25-30% are constituted by interest organisations, research institutions, authorities, finance and investment actors.

Figure 14: Types of actor organisations. Source: EIS Survey 2016, N=384.



The EIS survey also contains data concerning the areas of renewable and low-carbon energy technology the actors primarily deal with, see Figure 15. Bio energy, wind energy, and energy efficiency technology constitute the relatively large areas with more than two hundred actors, while wave energy, geothermal energy, fuel cells & hydrogen technology and CO_2 capture & storage are smaller with less than hundred actors. Solar energy is in-between and has grown significantly over the last five years.

Figure 15: Primary technology area of the actor organisations. Source: EIS Survey 2016, N=365.

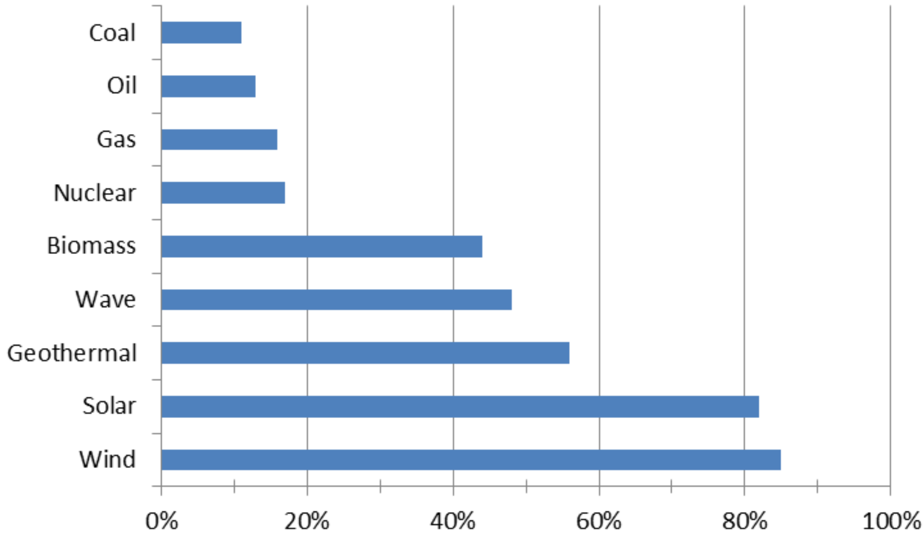


3.1.3 Public opinions

Public opinions about energy systems and the different types of energy technologies can be seen as indicators of the general 'climate' and conditions for energy innovation. More specifically, the opinions can be considered a measure of the legitimacy and the public acceptance and support of the different energy technologies. Data about public opinions can be found in opinion polls on national or European level (e.g. Eurobarometers). The opinion polls are unfortunately not repeated on a regular basis.

In the case of Denmark, a number of polls have in the recent years shown that there is significantly more support for renewable energy technologies than for fossil fuels and nuclear energy. In addition, they show that wind and solar energy are more popular than other types of renewable energy like, e.g., biomass energy and wave energy.

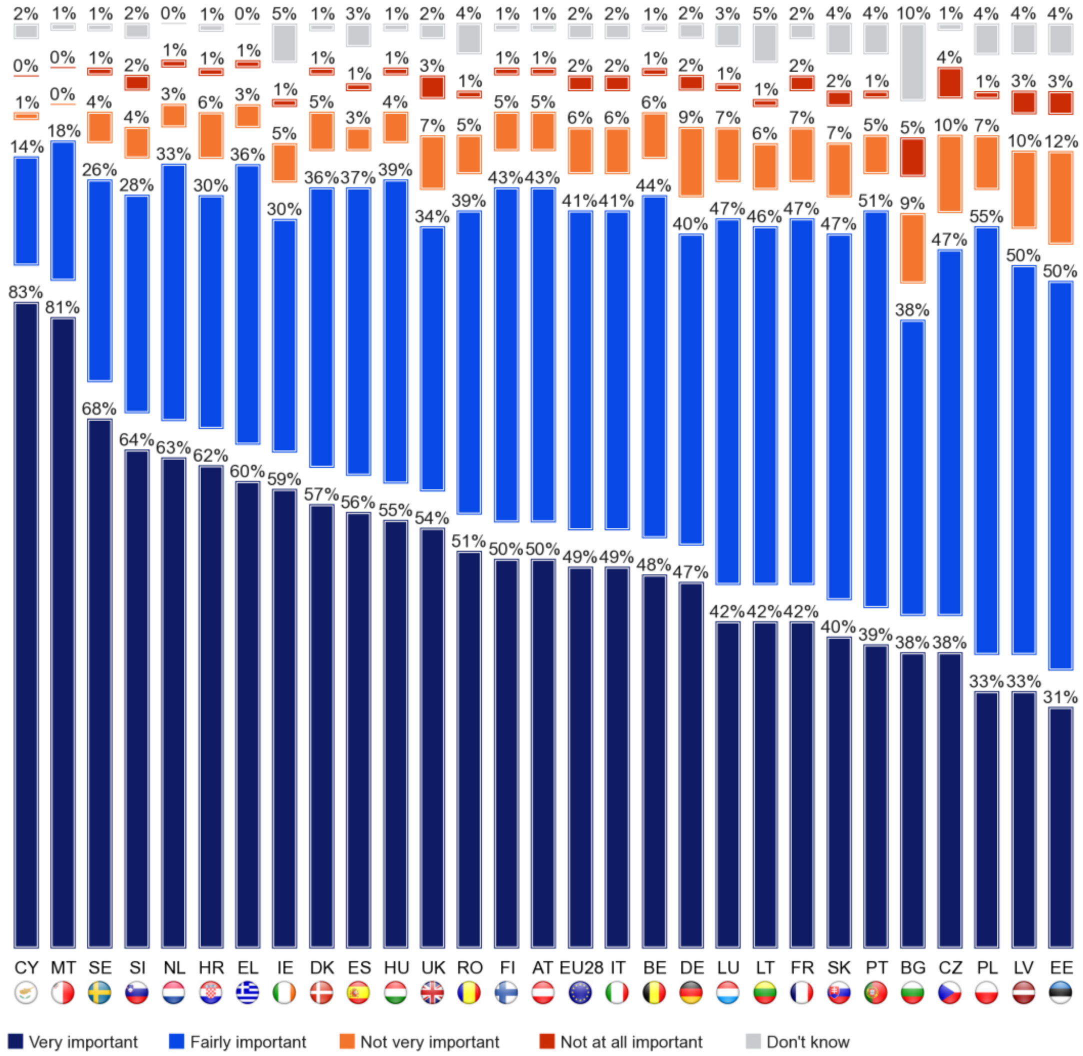
Figure 16: Public opinions in Denmark 2015: Which energy forms shall be prioritized in Denmark? (Megafon 2015, our translation).



The picture from Danish polls is confirming earlier results from EU polls (EC 2007). They showed that there are differences between the public opinions in the different EU countries and that the Danish population is among those most clearly in favour of renewable technologies like solar, wind and biomass energy (and opposing fossil fuels like coal, despite the fact that fossil fuels are used relatively much in the Danish energy systems).

A more recent Eurobarometer shows that most EU citizens find that it is important that national governments set targets to increase the amount of renewable energy used in order to combat climate change, see Figure 17. The importance is in Denmark indicated to be a bit higher that in EU in average. It is also worth noticing that the awareness about the issue is relatively high (few 'don't know' answers). This is the case for Denmark as well as a number of other countries including the other Nordic countries covered: Finland and Sweden.

Figure 17: Public opinions on renewable energy in the European Union: How important is it that the national government sets targets to increase the amount of renewable energy used, such as wind and solar power, by 2030? (EC 2014).



3.2 Throughput measures

3.2.1 Bibliometric – based measures for scientific publishing

Bibliometric-data is traditionally based on scientific publications and includes information on the type of publication, title, authors and their location, etc. Bibliometric data provides insight into the production of scientific literature in a given field and can be used to gauge the contributions in a given discipline by scientists working in a given country. It is possible to use also other types of data such as social media or web links, but we concentrate here on scientific publications. It is an established throughput indicator as bibliometric-based measures explore the intermediate production of the innovation process, especially those resulting at early stages of the innovation process.

Compiling and comparing data of relevant literature published by national scientists provides the basis for other indicators in addition to intermediate production of the innovation process. For example, the concentration of publication in given fields can be used as a further measure of the intensity of scientific activity; the degree of citations to given articles can be used as a measure of scientific impact; and the co-authorship patterns can be used to investigate collaboration and cooperation. The scoreboard report could not provide such data (Klitkou et al., 2010). For the purpose of this report, we concentrate on the volume of publishing by technology field and on international co-authorship patterns of Danish authors.

Bibliometric data have been extracted from the ISI Web of Science database, Core Collection provided by Thomson Reuters using keywords tailored to each technology field (a list is found in the annex). We propose to use the Science Citation Index and Social Science Citation Index and to include the following document types: article, editorial material, meeting (or proceeding) paper and review.

The application of bibliometric data hinges on the definition of keywords. We propose to apply revised search strings based on key words for each technology field as they have been developed in 2007 for the eNERGIA project (Klitkou et al., 2008), but have been updated for the first project report published in 2012. For enabling an analysis of the changes, we applied basically the same keywords for this updated report. The keywords are used to check titles, author keywords, abstracts and keywords added by the database provider. A major change in the results is the dominant position of the Peoples Republic of China: Danish researchers co-publish with Chinese researchers and this cooperation has taken over a leading position in several fields of energy research.

We use fraction counts of publications. This means that every paper counts only once and different author addresses receive their respective share of this paper. If the article lists two addresses then each address receives 0.5 points, for three addresses every address receives 1/3 points a. s. o.

There are also potential limitations to the use of this type of data. The delineation is also important here, because in several fields it is necessary to avoid many ‘false friends’, such as both in wind energy and solar photovoltaics many articles would stem from astrophysics.

Table 5: Scientific publishing 2011-2015. Sources: ISI Web of Science. Based on fraction counts.

	2nd generation bio-fuels	Fuel cells	Photovoltaic	Wind
Denmark	191,7	159,5	226,9	508,8
Finland	118,5	42,1	209,5	55,4
Norway	72,5	32,7	203,0	213,1
Sweden	228,3	73,5	576,3	159,5
Iceland	0	0	0,1	3,5

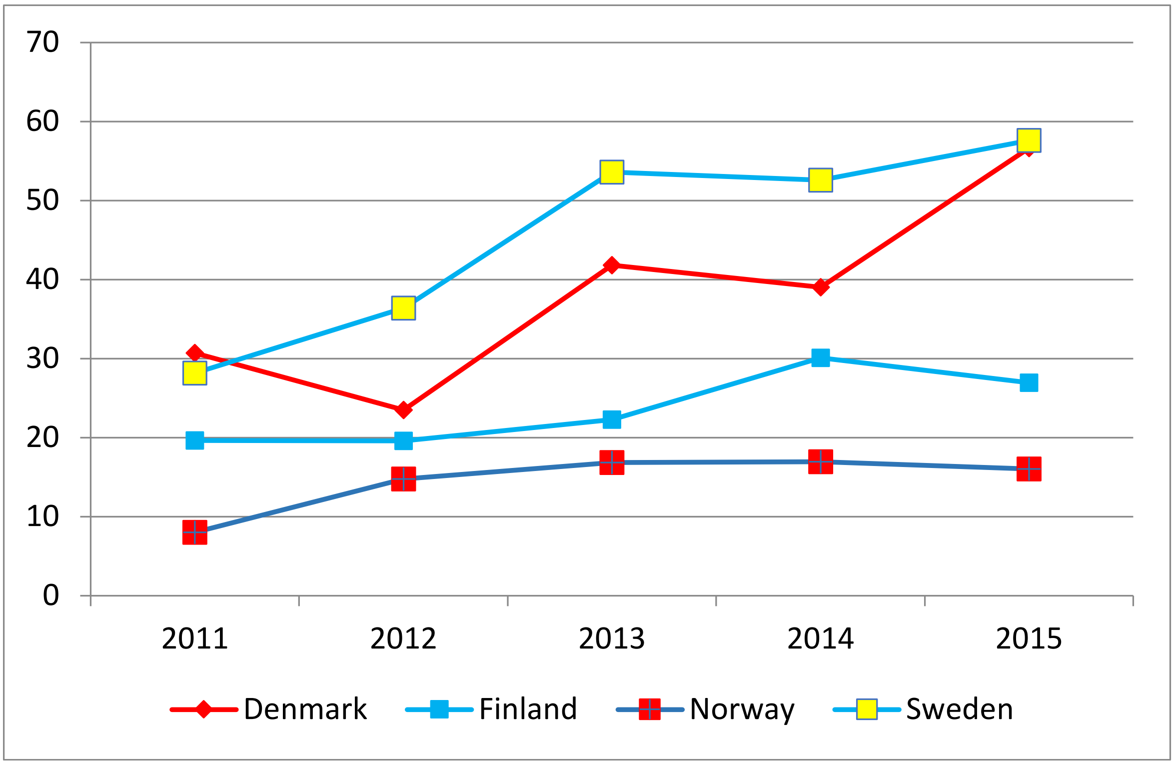
Note: Included document types: article, review, proceeding paper, editorial material.

Table 6: 2nd Generation bio-fuels: Publishing for the Nordic countries 2011-2015. Based on fraction counts (N=833).

	2011	2012	2013	2014	2015	Total
Denmark (N=274)	30,7	23,5	41,8	39,0	56,7	191,7
Finland (N=153)	19,6	19,6	22,3	30,1	26,9	118,5
Iceland (N=0)	0	0	0	0	0	0
Norway (N=103)	8,0	14,7	16,8	16,9	16,0	72,5
Sweden (N=303)	28,2	36,4	53,6	52,6	57,6	228,3
Total (N=833)	86,5	94,2	134,5	138,6	157,2	611,0

Note: Total counts in parentheses. Iceland had no publications.

Figure 18: 2nd Generation bio-fuels: Publishing for the Nordic countries 2011-2015. Based on fraction counts (N=611).



Authors with at least one Danish address published 274 articles on 2nd generation (2G) biofuels, 144 or 53% were internationally co-authored (based on total counts). The main co-authoring countries are the USA, the Peoples Republic of China and Sweden (Table 7, based on fraction counts)

Table 7: Top 10 countries Denmark co-published with in 2G bio-fuels. Based on fraction counts (N=274).

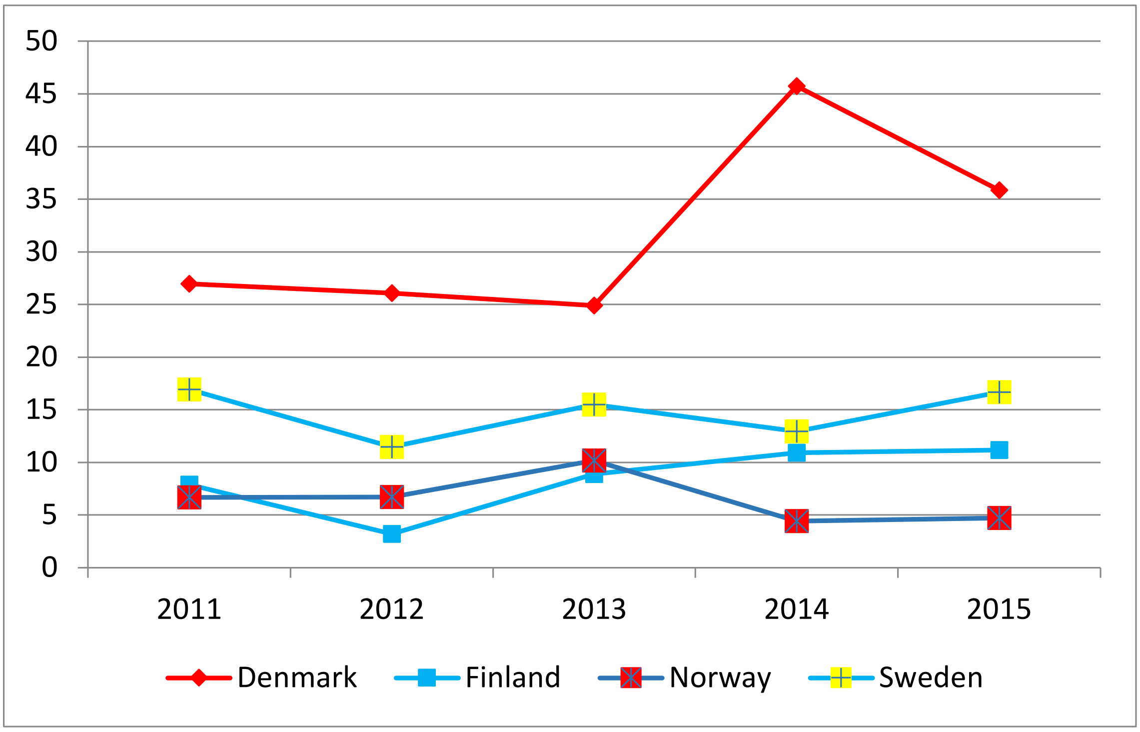
Sum of fractionised shares	Top 10 countries
15,6	USA
7,6	Peoples R China
6,5	Sweden
6,1	Greece
3,8	Norway
3,3	Italy
3,2	Spain
3,0	Germany
2,9	UK
2,6	Malaysia

Table 8: Fuel cells: Publishing for the Nordic countries 2011-2015. Based on fractionalized counts (N=403).

	2011	2012	2013	2014	2015	Total
Denmark (N=199)	27,0	26,1	24,9	45,8	35,9	159,5
Finland (N=58)	7,9	3,2	8,9	10,9	11,2	42,1
Iceland (N=0)	0,0	0,0	0,0	0,0	0,0	0,0
Norway (N=50)	6,7	6,7	10,2	4,4	4,7	32,7
Sweden (N=113)	16,9	11,5	15,5	13,0	16,7	73,5
Total (N=403)	58,5	47,5	59,5	74,0	68,4	307,8

Note: Total counts in parentheses.

Figure 19: Fuel cells: Publishing for the Nordic countries 2011-2015. Based on fraction counts (N=403).



Authors with at least one Danish address published 199 articles on fuel cells, 72 or 36% were internationally co-authored (numbers are based on total counts). The main co-authoring countries are Germany and the Peoples Republic of China (Table 9).

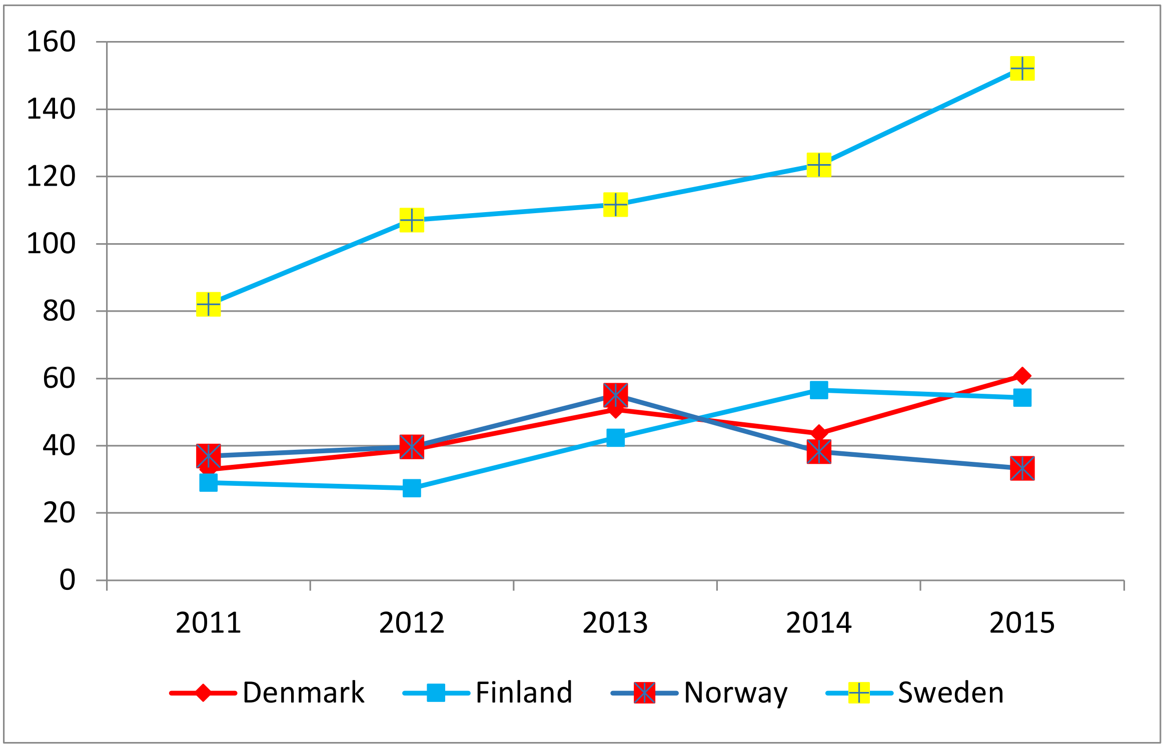
Table 9: The top 10 countries Denmark is co-publishing with in fuel cells. Based on fraction counts (N=72).

Sum of fraction shares	Top 10 countries
6,2	Germany
4,3	Peoples R China
3,2	Spain
3,1	USA
2,8	Sweden
2,6	Switzerland
2,5	Korea
2,3	Finland
1,9	Italy
1,8	Austria

Table 10: Photovoltaic: Publishing for the Nordic countries 2011-2015. Based on fraction counts (N=1962).

	2011	2012	2013	2014	2015	Total
Denmark (N=376)	32,9	38,9	50,7	43,7	60,7	226,9
Finland (N=332)	29,0	27,3	42,4	56,5	54,3	209,5
Iceland (N=1)	0,1	0	0	0	0	0,1
Norway (N=314)	36,9	39,6	55,0	38,2	33,3	203,0
Sweden (N=1008)	82,1	107,0	111,7	123,4	152,1	576,3
Total (N=1962)	181,0	212,8	259,8	261,7	300,4	1215,8

Figure 20: Photovoltaic: Publishing for the Nordic countries 2011-2015. Based on fraction counts (N=1962).



Authors with at least one Danish address published 376 articles on photovoltaic energy, 233 or 62% were internationally co-authored (numbers are based on total counts). The main co-authoring countries are the Peoples Republic of China, the US and Germany (Table 11).

Table 11: Top 10 countries Denmark is co-publishing with in photovoltaic energy. Based on fraction counts (N=233).

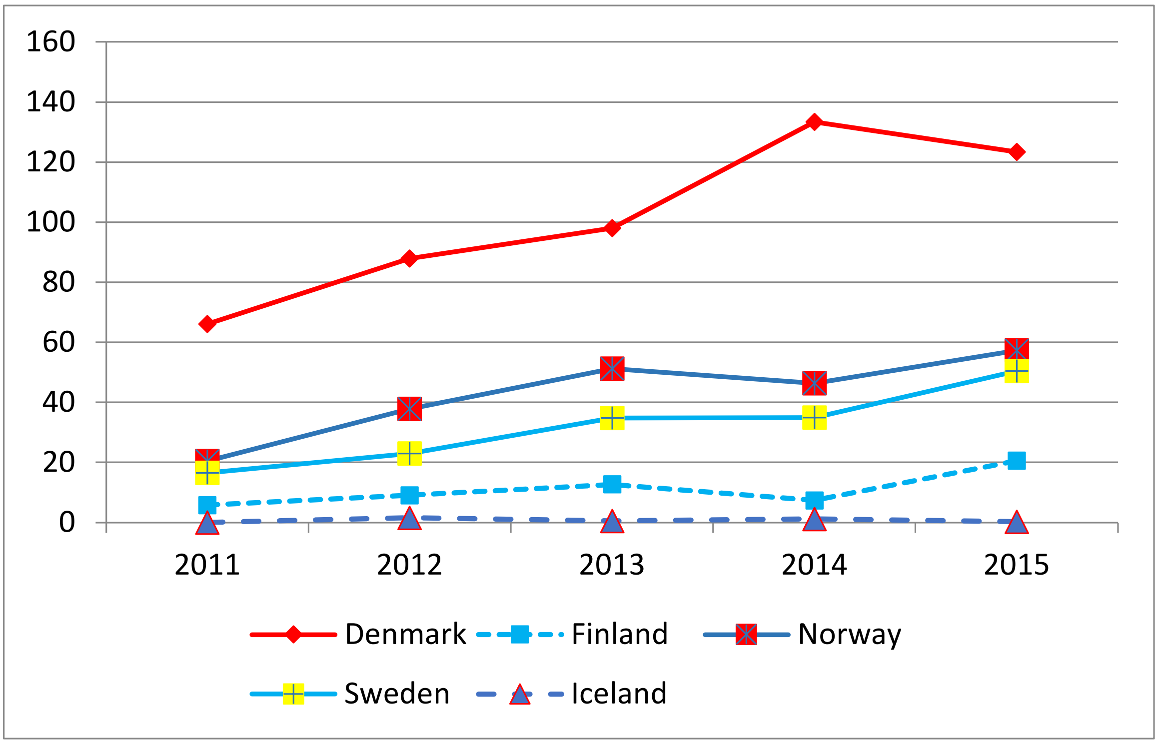
Sum of fraction shares	Top 10 countries
23,1	Peoples R China
23,1	USA
18,1	Germany
11,3	UK
8,1	Spain
7,9	Netherlands
6,6	Sweden
6,0	France
4,5	Italy
4,0	Australia

Table 12: Wind energy: Publishing for the Nordic countries 2011-2015. Based on fraction counts (N=1223).

	2007	2008	2009	2010	Total
Denmark (N=719)	66,0	87,9	98,1	133,4	123,4
Finland (N=79)	5,8	9,1	12,7	7,4	20,6
Iceland (N=7)	0,0	1,6	0,5	1,2	0,3
Norway (N=283)	20,5	37,9	51,2	46,3	57,2
Sweden (N=210)	16,6	22,9	34,7	35,0	50,4
Total (N=1223)	108,8	159,3	197,2	223,2	251,8

Note: Total counts in parentheses.

Figure 21: Wind energy: Publishing for the Nordic countries 2011-2015. Based on fraction counts (N=1223).



Authors with at least one Danish address published 719 articles on wind energy, 372 or 52% were internationally co-authored (numbers are based on total counts). The main co-authoring countries are the People's Republic of China and the USA (Table 13).

Table 13: The top 10 countries Denmark is co-publishing with on wind energy. Based on fraction counts (N=372).

Sum of fractionised shares	Top 10 countries
35,1	Peoples R China
27,1	USA
19,5	UK
19,0	Germany
11,4	Norway
11,0	Spain
8,7	Netherlands
8,5	Sweden
8,4	Italy
6,6	Ireland

3.2.2 Patents and low-carbon energy technologies

In reporting on patents and low-carbon energy technologies, this section builds on and updates the original report. The previous report was among the first publications to use the European Patent Office's newly introduced categorization system for environmental technologies. The system had the purpose to reliably identify 'environmentally sound technologies' (est). It was launched in the 2009b edition of Patstat which we used.[2] Patstat has since grown to become the most widespread and most comprehensive source of patent statistics, while the EST tags have become further integrated and developed in the emerging standard classification among the major patent offices, the CPC.[3]

This follow-up edition integrates the improvements in the classification system while providing counts of patent-families and the earliest filing ('priority') date. As indicated in the last report, this selection process is the best way to avoid double-counting of applications that may use a variety of filing routes (national or regional) to protect the same invention. We also focus on the country of the assignee. This provides a slightly more restrictive identification process than the one employed in the last edition which was based on all applications. Please see Annex 4 on "Data and Extraction" for further detail.[4]

In the original report we discussed using patents to monitor emergent technologies:
Patents provide a promising proxy to capture ongoing research activity in the field of low-carbon technologies. A patent is an indication of inventive activity that has yielded a technology that is new to the field and that has an assumed commercial potential. Indicators based on patenting activity can for example be used to better understand the innovative activities taking place in the private sector. They can also provide an idea of actors (by country or type) who are actively innovating in these technological areas, the degree to which they collaborate, technology transfer, etc.

However, patent data do not reflect the commercialisation of the patents. Therefore, they are throughput indicators. There are also some challenges connected to using patent data as an indicator for innovation. Increased patenting activities of public research organisations can endanger the access to new knowledge by other firms; and the diffusion of the patented inventions may be hindered if they are not supported by patent pools and clear licensing guidelines. Too broad protection on basic inventions can discourage follow-on inventors (OECD, 2004). Other non-proprietary means of disseminating knowledge, such as standards, may contribute to innovation in a more appropriate way.

The OECD study highlighted that patents play a decisive role in a few industries, such as biotechnology, drugs development, chemicals and machinery and computers, while other industry sectors use other forms of protection their intellectual property, such as "secrecy, market lead, advance on the learning curve, technological complexity and control of complementary assets" (OECD, 2004, p. 9). Low carbon energy technologies encompass rather different fields of technology: from biotechnology for producing biofuels and chemistry for carbon capture towards material science for almost all technologies. The propensity to patent is different for the different fields of technology and we assume that the role of patenting is also different (Source: the previous EIS Indicator Report (Klitkou et al., 2012), chapter 3.2.2.).

Applying this classification system for environmental technologies, the section provides an indication of inventive activity for the period 1998-2012 for the following technologies:

- Solar Energy
- Wind power
- Bio energy
- Hydro power
- Combustion technologies with mitigation

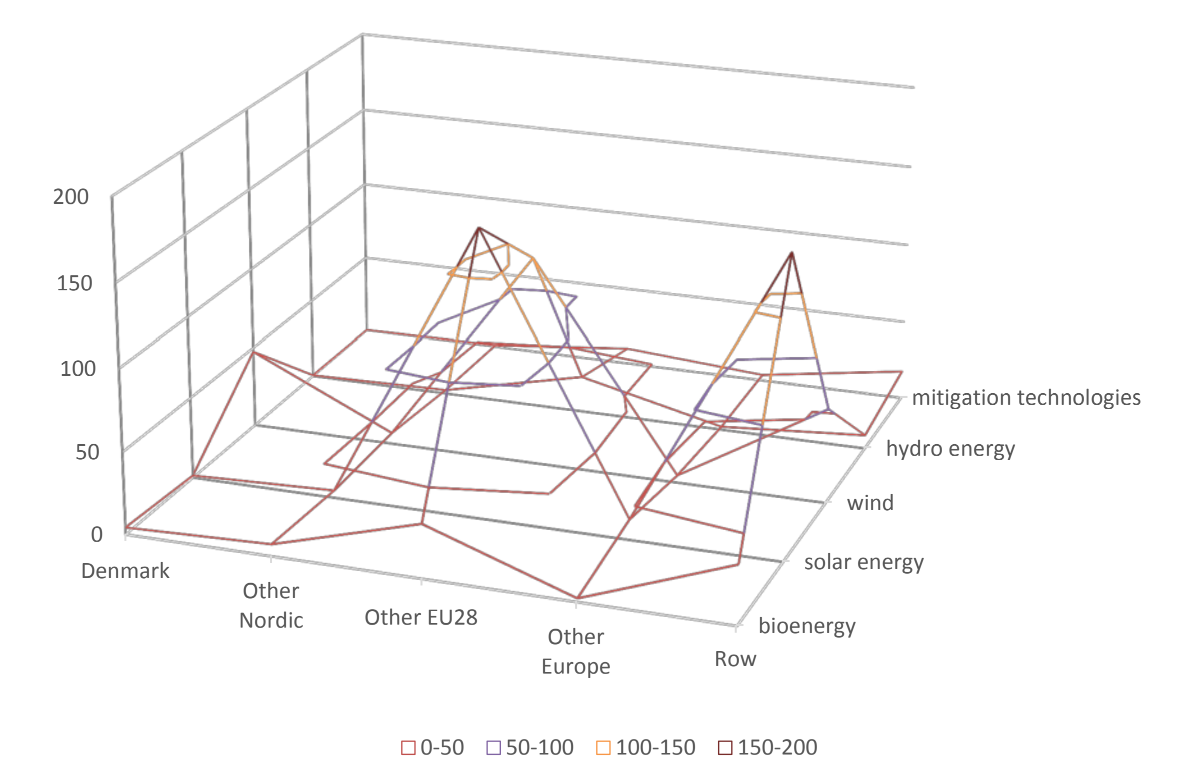
[2] EPO Worldwide Patent Statistical Database (PATSTAT).

[3] See www.cooperativepatentclassification.org

[4] Three adjustments should be noted. The first is that the last edition used applications unified by earliest priority dates. The approach opens for some double-counting. Second, the original approach allocated patents based on the country of the inventor rather than that of the assignee. The third is that adjustments have been made in the categorization system ("y tags") which may affect the inclusion criteria in particular cases, such as carbon-capture and storage. See above.

You will find the definitions in Annex 5. The composite view that emerges is presented in Figure 22 for a given year (2011). The presentation illustrates the general patent landscape for these technologies.

Figure 22: Patent families applied for in Europe with earliest filing date (2011), by assignee



Figures 23-27 on the following pages show results for the individual technologies. The first figure reflects that, in the period 1998-2012, a total of 38 patent families in bio-energy technologies that involved Danish applicants and a further 43 that involved applicants from the other Nordic countries appeared.

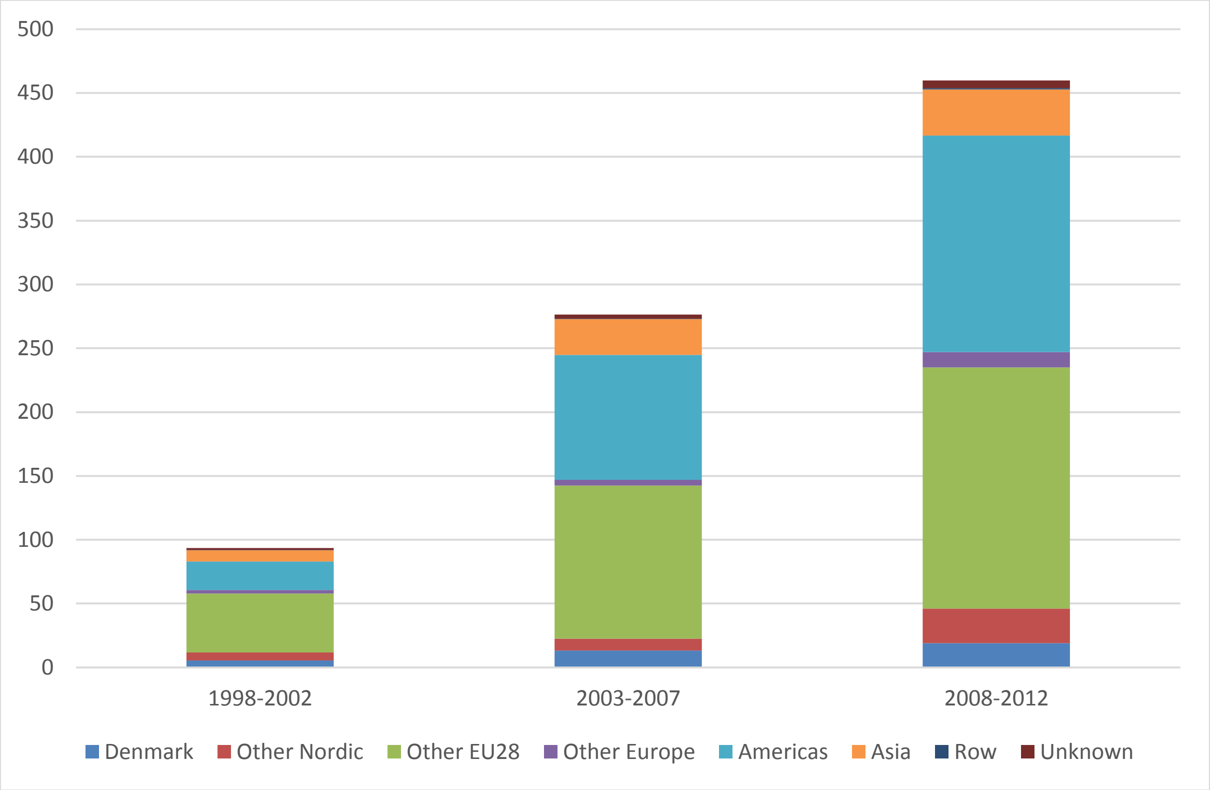
In the figure on solar technologies the Danish contribution is almost invisible. In the period 1998-2012, a total of 13 patent families in solar technologies involving Danish applicants and 38 involving applicants based in the other Nordic countries appeared.

Figure 25, on wind technologies, reflects that in the period 1998-2012, Danish applicants account for a total of 232 patent families in wind technologies. A further 54 patent families originated from applicants in the other Nordic countries. Danish patenting in this area has been consistently strong through the period, and it expands remarkably in the last five-year period as does that of other EU28 countries.

Nordic patenting in hydroelectric technologies (Figure 26) is remarkably limited. There was a total of 19 Nordic patent families in this technological area during the 15-year period (1998-2012). Three of these involved Danish applicants.

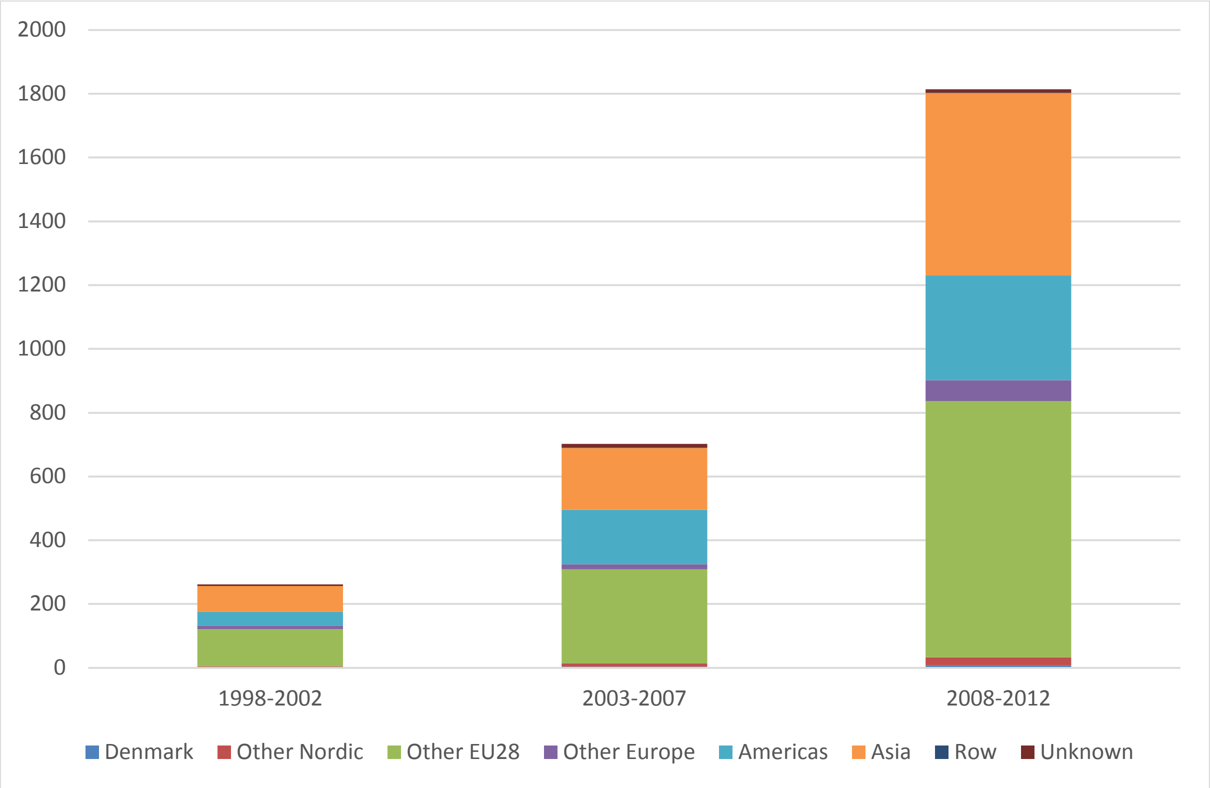
Finally, Figure 27 reflects that there were 20 Nordic patent families in mitigation technologies during the 15-year period (1998-2012). Six of these originated in Denmark.

Figure 23: Bio-energy patent families applied for in Europe with earliest filing date, by assignee



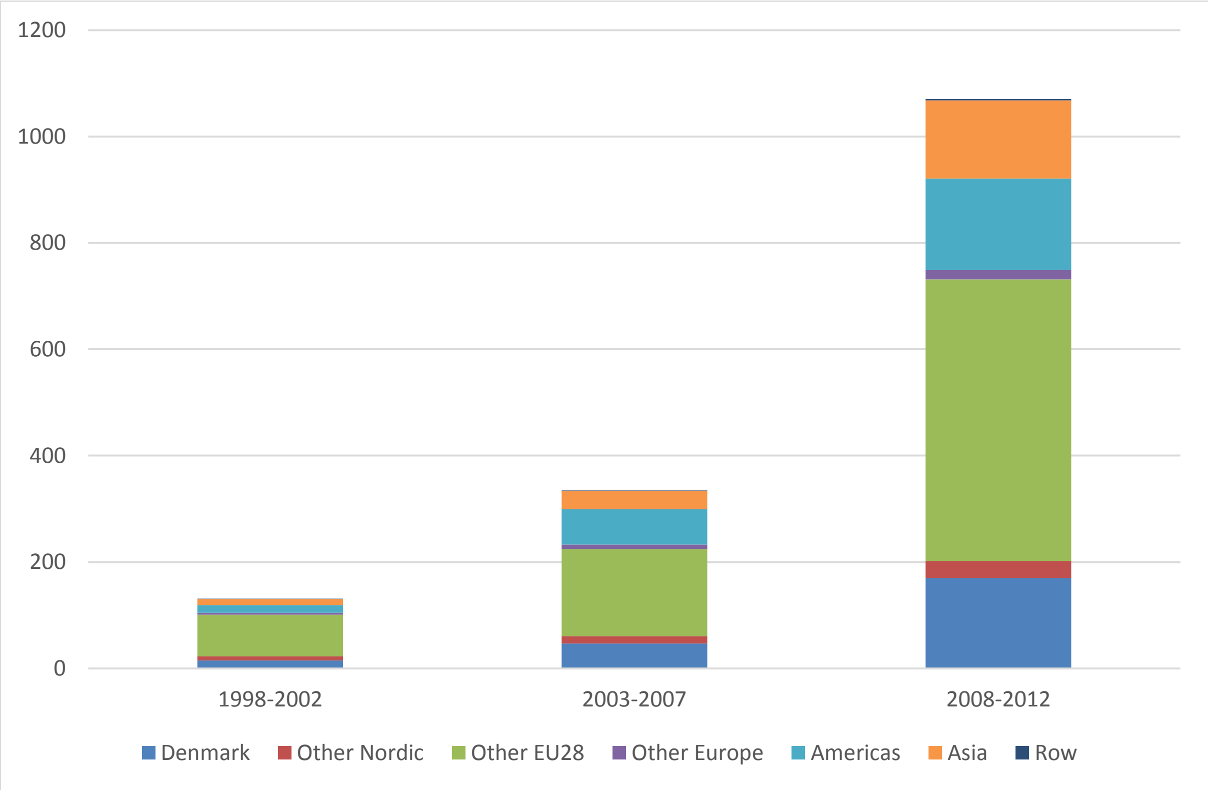
*Patstat (2015b)

Figure 24: Solar technologies patent families applied for in Europe with earliest filing date, by assignee



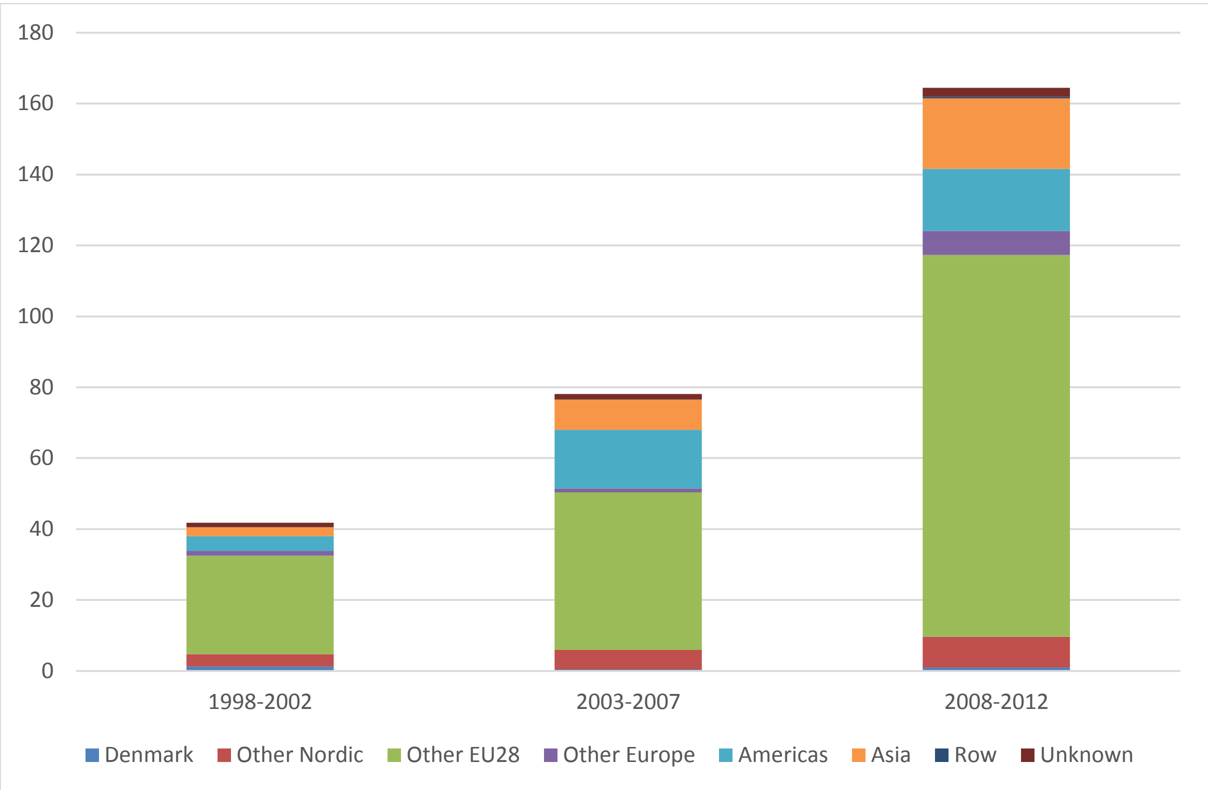
*Patstat (2015b)

Figure 25: Wind technologies patent families applied for in Europe with earliest filing date, by assignee



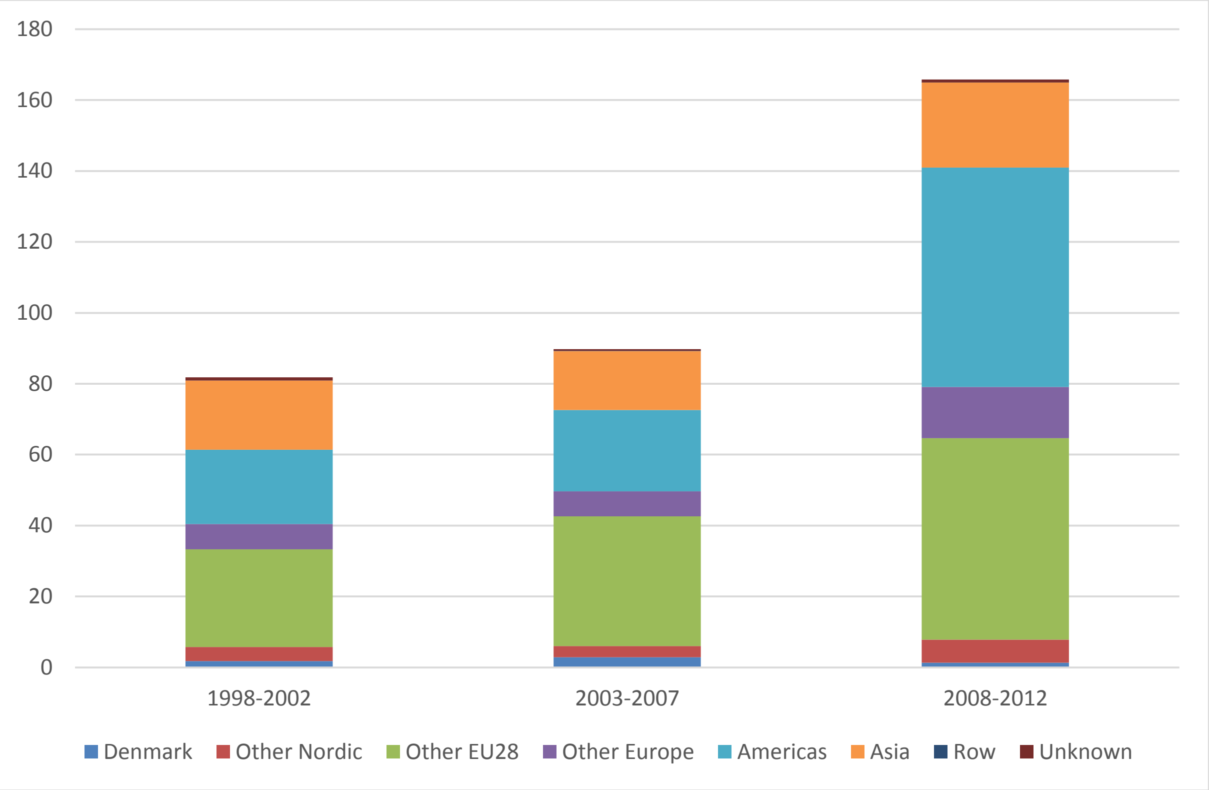
*Patstat (2015b)

Figure 26: Hydro energy patent families applied for in Europe with earliest filing date, by assignee



*Patstat (2015b)

Figure 27: Mitigation technologies patent families applied for in Europe with earliest filing date, by assignee



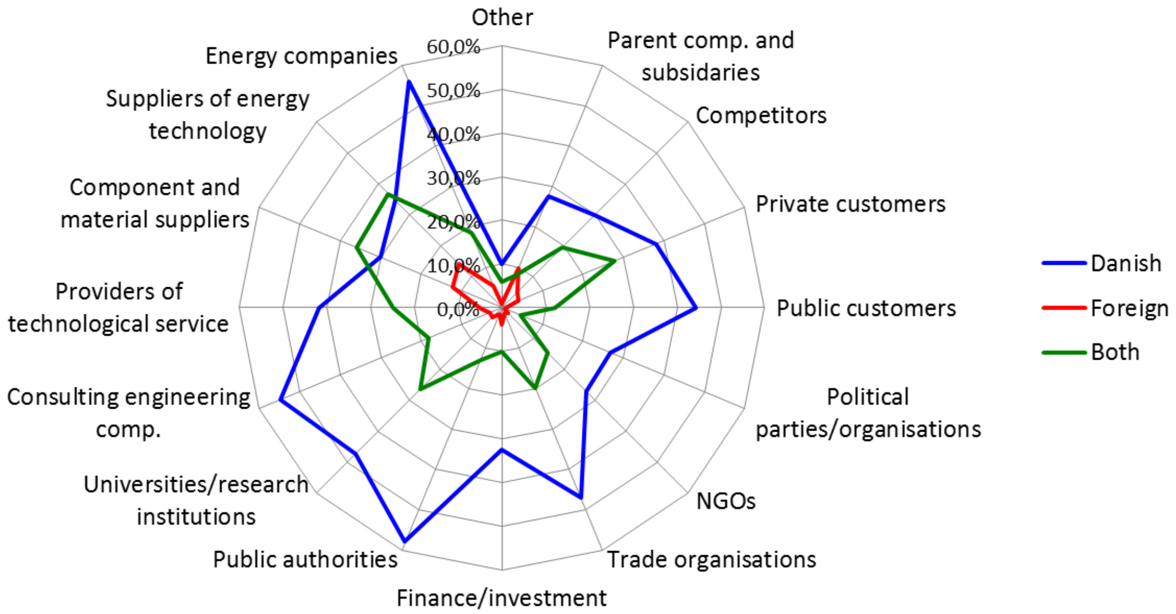
*Patstat (2015b)

3.2.3 Cooperation and interaction

Indicators of cooperation and interaction have been suggested in a number of research projects in recent years. Some are measured based on the relations of the individual actor organisations in the energy innovation system while others use projects in public research, development and demonstration (RD&D) programmes as basis. Figure 28 shows results from the latest version of the EIS survey which is based on the relations of individual actors (Borup et al., 2016). It appears, for example, that more than 50% of the actors in the Danish energy innovation system had cooperation with energy companies in Denmark.

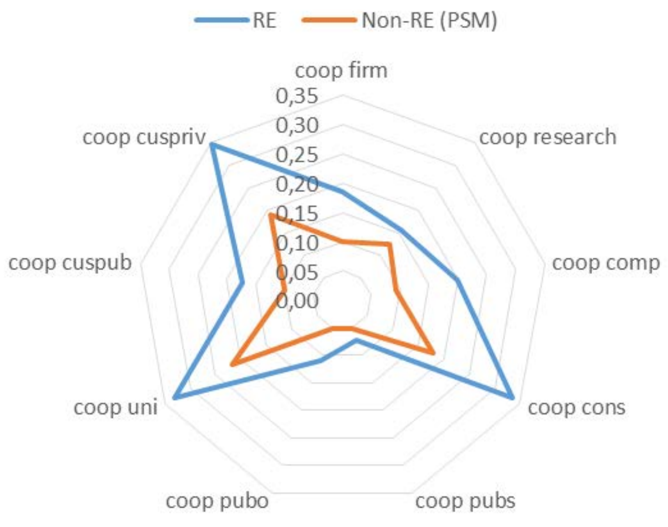
The figure moreover illuminates to what degree the actors participate in cooperation with domestic partners, with partners from abroad, or both. Hence, it is also an indication of how much of the cooperation in the energy innovation system that is internal Danish interaction and how much that is international interaction. The internal Danish interaction is clearly dominating the picture.

Figure 28: Pattern of cooperation in Danish energy innovation, type of cooperation partners over the period 2014-2015, Danish or foreign partners, EIS Survey 2016, N=384



Another analysis compares the cooperation patterns of innovative firms within renewable energy with the cooperation patterns of other innovative firms in Danish industry (Christensen et al. 2016). The data set used is from a special section of the general innovation statistics (CIS) in Denmark in 2014. The results show that firms within renewable energy more often cooperate with other organizations than firms in other areas do, see Figure 29. The difference is significant concerning all types of cooperation partners. Apart from with public service institutions and research institutions, cooperation is around twice as frequent within renewable energy as in other areas.

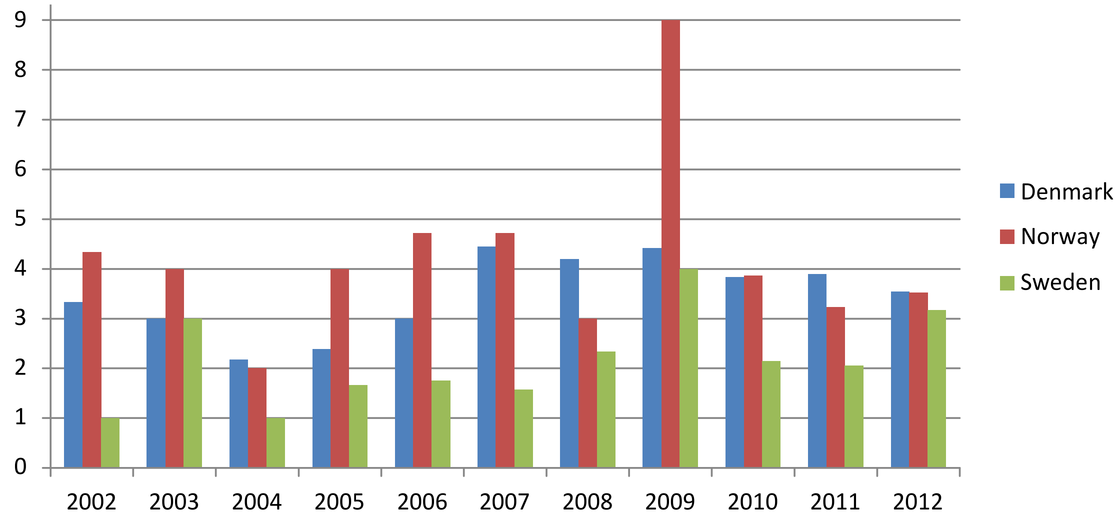
Figure 29: Cooperation pattern of innovative firms within renewable energy (RE) and within other, 'non-green' areas (Non-RE) in Denmark (Christensen et al. 2016). N=290 for RE as well as Non-RE.



Notes: Cooperation with: firms from other sectors (firm), competitors (comp), research institutions (research), consultants and other private business service (cons), public service institutions (pubs), universities (uni), other public sector institutions (pubo), public sector customers (cuspub), and private sector customers (cuspriv). A propensity-score matching procedure (PSM) is used: every RE innovating firm is matched with a non-RE counterpart, similar in number of employees, R&D expenses per employee, industry affiliation, age, and regional location.

The number of energy related projects in public research, development and demonstration programmes has in recent years been considerable. In Denmark, more than a hundred projects has been granted a year since 2003 (according to data from www.energiforskning.dk). This makes the project activities a vital factor in the energy innovation system and an important place for cooperation. The technology- and organisation-specific analyses of RD&D projects that were available for the previous version of this report have unfortunately not been repeated. A recent analysis of demonstration projects within energy and transport in the Scandinavian countries, however, confirms the earlier findings of considerable cooperation in the project activities and, moreover, that cooperation is more frequent in Norway and Denmark than in Sweden, see Figure 30.

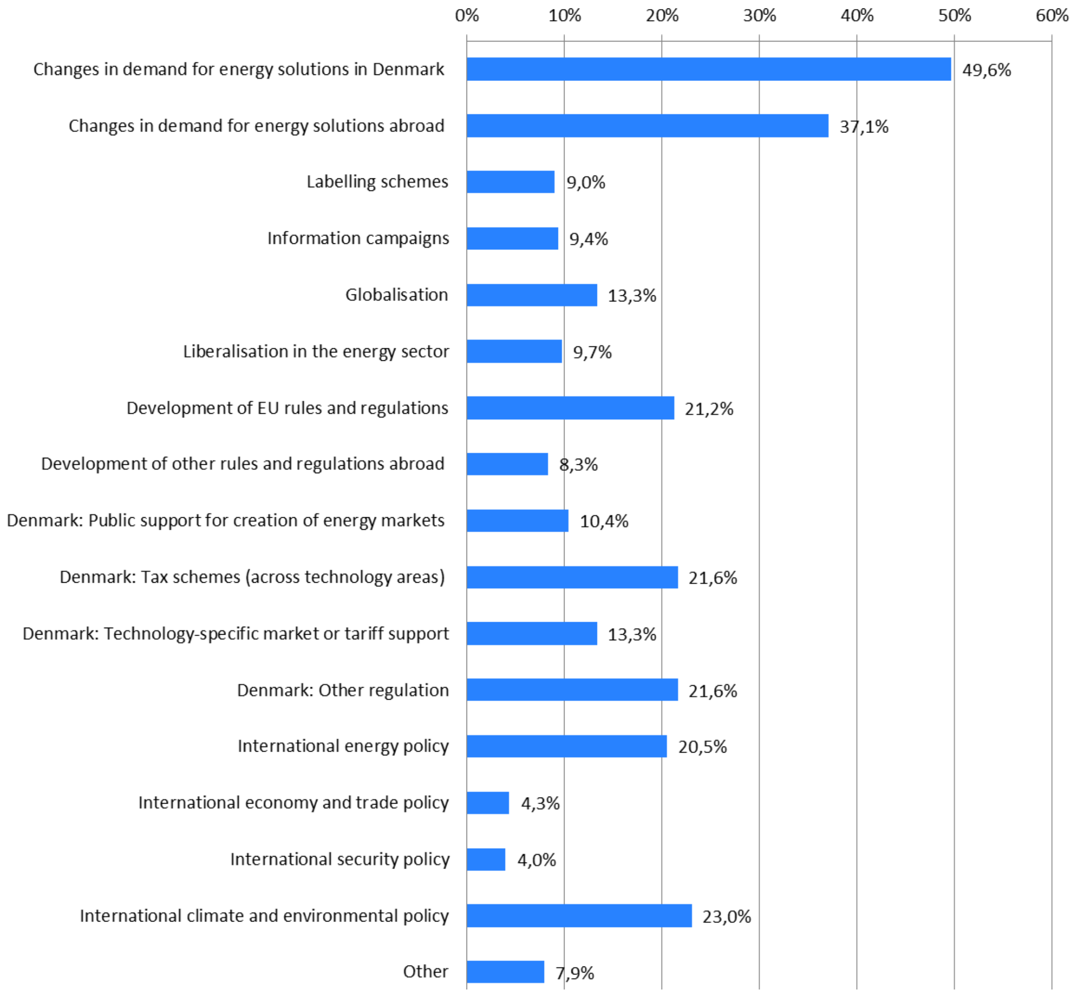
Figure 30: Average number of partners in demonstration projects within energy and transport in Scandinavian countries (Andersen et al. 2014). Inno-Demo database, N= 433.



3.2.4 Market developments as driving factor for innovation

Developments in market demands can be an important driving factor for innovation. This type of through-put indicator is also illuminated in the EIS Survey (Borup et al., 2016). Among other things the sources of the market developments in the recent years are analysed, building on identification by actors in the Danish energy innovation system. The majority of actors (>70%) experienced a significant market development in connection to their activities on energy technology development. The sources of the market developments are identified as shown in the following figure. It appears that developments in demand on primarily the domestic Danish market, but also on foreign markets are important. Of the more specific factors behind the market changes, the developments in policy and regulation on Danish, EU and international levels are the most important.

Figure 31: Sources of market developments as driving factor for innovation. (Share of actors that experienced the different sources.) EIS Survey 2016, N=278.



3.3 Output measures

3.3.1 Application of low carbon technologies – domestic use

Market application of new low-carbon technologies and solutions is among the most direct indicators of output from the energy innovation system. It can be measured in economic terms as it is done in the industry and trade statistics shown later. Or it can be measured in technical terms, e.g., the amount of products sold, the amount of energy produced by the low-carbon technologies or the amount of installed capacity in the energy systems.

National energy statistics make up a good source of data for the latter type of indicators, as they in many countries include data on the use of different types of energy production technologies in the domestic energy systems. Figure 32 shows the development in the use of different types of renewable energy technologies in the energy production in the Danish energy systems over the latest decades. It is seen that biomass based energy constitutes the majority of renewable energy produced in Denmark. Also wind energy constitutes a considerable share. Of the rest of the covered technologies, heat pumps and biogas are the most used technologies.

Figure 32: Renewable energy production in Denmark, TJ. Source: ENS (2015).

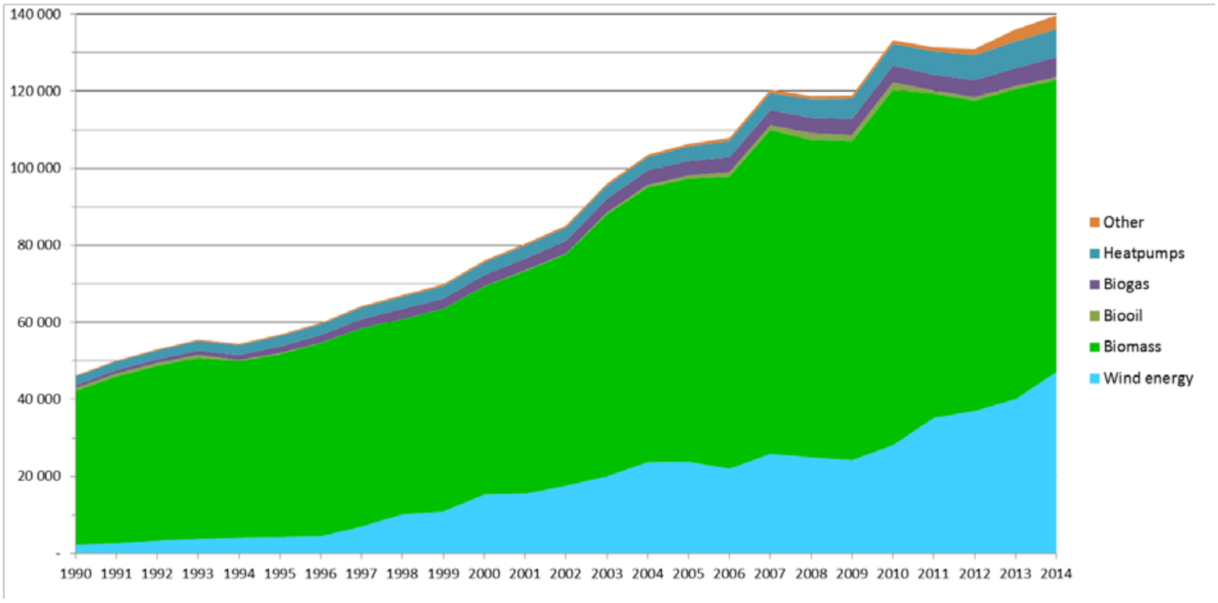
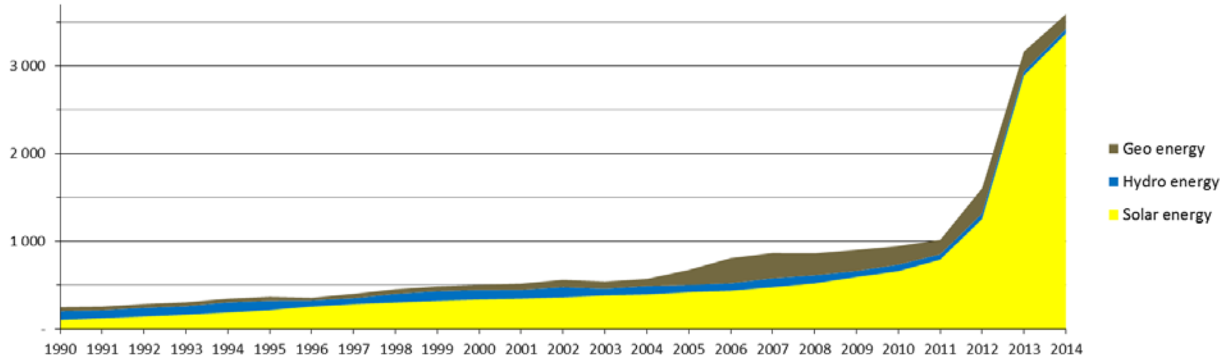


Figure 33 shows an enlarged picture of the smallest renewable energy production technologies (included in 'Other' in the previous figure). The use of solar energy has increased significantly in recent years. Taken over a 20-years period, hydro energy is the only one of the renewable energy technologies covered which use has not grown. Geothermal energy has varied considerably though.

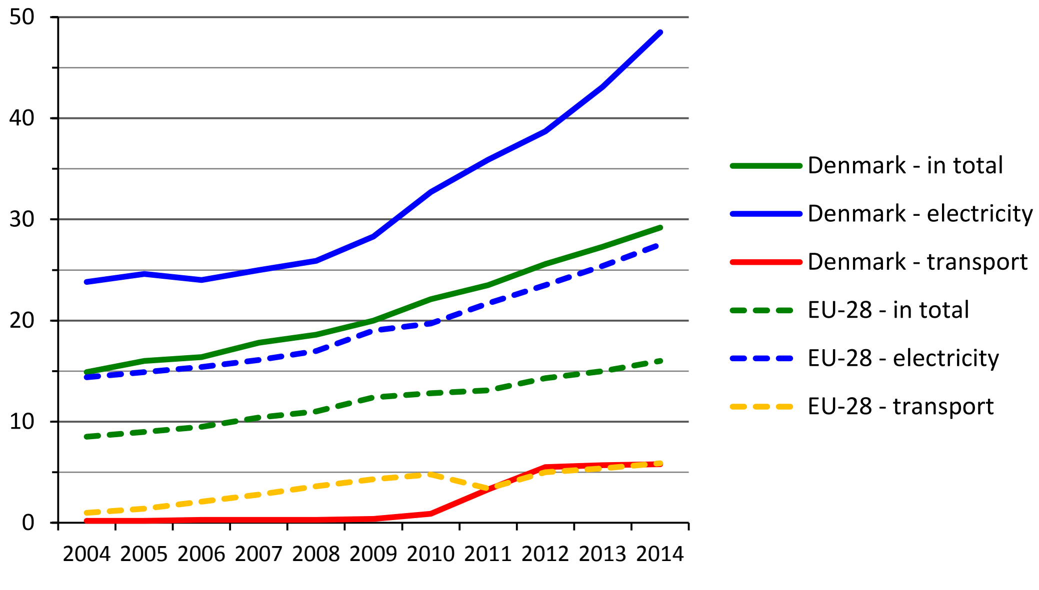
Though the production of renewable energy has tripled since 1990, the relative share of renewable energy in the primary energy production has only increased from around 11% to 20% over the period, due to increase in also other types of energy production, not least natural gas and oil (ENS, 2015). The gas and oil production peaked in the middle of the 00s and has decreased since then. A significant amount of the produced gas and oil is exported.

Figure 33: Renewable energy production in Denmark – the small ones, TJ. Source: ENS (2015).



If one considers the greening of the national energy systems as an output indicator of the energy innovation systems, it can also be relevant to look at the share of renewable energy in the consumption of energy. In the total consumption of energy, the share has increased from 6-7% in 1990 to 29% in 2014 (ENS, 2015), see also Figure 34. If one looks specifically at electricity, the share doubled from 24% in 2004 to 48% in 2014. The share of renewable energy consumption within transport is still small, though it rose quickly to the EU target of 5% from 2010 to 2012. The increasing renewable energy shares mean that a market- and use-based learning about renewable energy technologies occurs in the Danish energy innovation system. Still, most of the energy comes from fossil fuels and it seems clear that a considerable market- and use-based learning also appear in these areas.

Figure 34: Percentage of energy consumption generated from renewable sources in Denmark and in the European Union: in total, in the electricity systems, and in transport. Source: Eurostat.

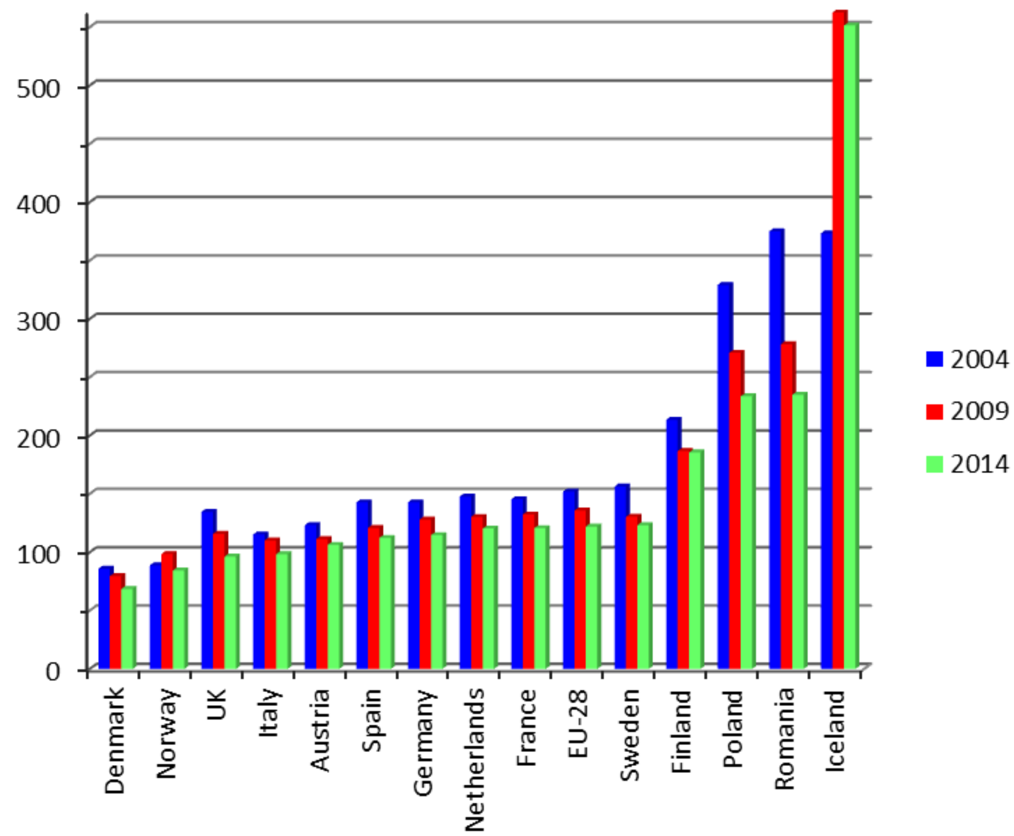


3.3.2 Application of energy efficiency technology

Domestic application of energy efficiency technologies is more difficult to measure in general than the application of renewable energy production technologies etc. addressed above. Energy efficiency issues appear in numerous product and application areas and energy efficiency is often a relative issue related to the already existing practices in the specific application areas. This makes it highly difficult to establish a general and homogeneous way of measuring the application of energy efficiency products in total. One possibility is to identify energy efficient product types in specific application areas and measure the extent of the application in these areas either in economic terms (trade of products) or in technical terms (amounts of units installed or energy consumption or efficiency figures). The product focused approach can be seen as a bottom up strategy where measuring can be made in a limited number of areas on micro level or sector level, but where it is difficult to get the full, macro-level picture.

Another, opposite, possibility is a macro level measuring strategy, where one uses macro level statistics on energy consumption and measures the developments in energy intensity, i.e., the developments in energy consumption in relation to developments in activities. The activities can on macro level be measured in GDP (gross domestic product). Figure 35 shows the energy intensity of selected European countries and EU-28. It can be seen that considerable efficiency changes appear in most countries over five-year periods. Denmark, Norway, and Ireland (not shown) are the most energy efficient economies and have an energy intensity that is significantly lower than other European countries.

Figure 35: Energy intensity of the economy - Gross domestic consumption of energy divided by GDP (kgoe per 1000 €). Source: Eurostat.

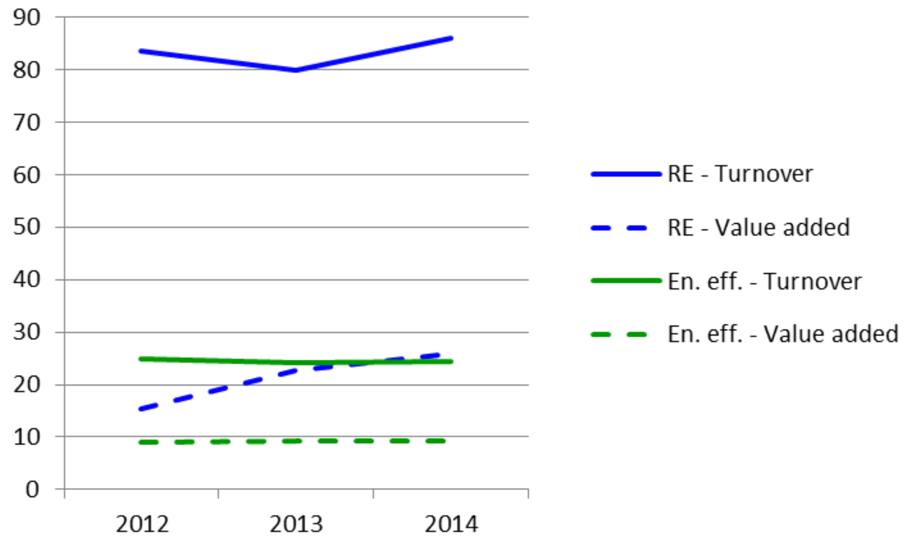


3.3.3 Industrial economy of energy technology products and services

Traditionally, industry and trade statistics have only to a limited extent been able to offer relevant indicators for energy innovation systems as the classifications of products and activities do not always include clear distinctions between energy and non-energy areas. Concerning the quest of moving towards sustainable energy systems, it is moreover a limitation that low-carbon and renewable energy technologies do not always appear in categories separate from other energy technologies.

The statistics on environmental goods and services that in recent years have been established in a number of European countries, including Denmark, provide accounts of goods and services for production of renewable energy ('production of energy from renewable resources') and energy efficiency ('heat/energy saving and management') (categories 13A and 13B of the CReMA classification system: Classification of Resource Management Activities). Figure 36 shows that the industrial turnover within renewable energy in Denmark was around 86 billion DKK in 2014. For energy efficiency the figure was around 24 billion DKK. The total value added is, seen relatively to the turnover, biggest within energy efficiency, but has increased considerably within renewable energy in the period 2012-2014. In absolute figures, it was 26 billion DKK in 2014.

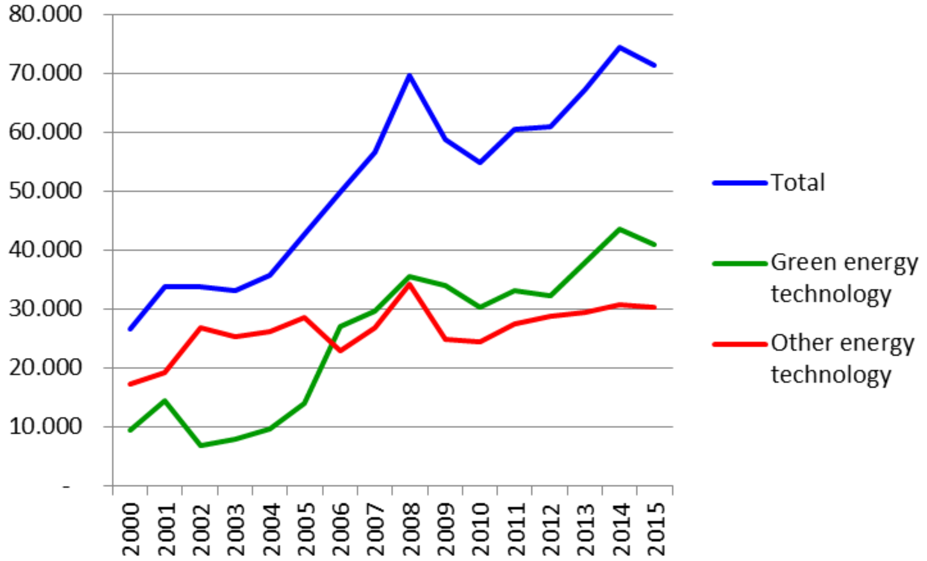
Figure 36: Turnover and value added of goods and services for production of renewable energy (RE) and energy saving and management (En. eff.) in Denmark. Billion DKK. Source: Statistics Denmark, statistics on environmental goods and services.



3.3.4 Energy technology exports

Energy technology export is one of the important output indicators for the energy innovation system. Different sources for export figures exist. Danish authorities have in collaboration with Danish Energy Industries Federation, Danish Energy Association, and Statistics Denmark established an energy industry statistics with figures for energy technology exports, see Figure 37. A significant increase in the export has appeared over the latest decade, though there is considerable variation from one year to another and the financial crisis clearly shows in 2009-2010. The increase appears primarily within green energy technology, that since 2006 has been bigger that the export of other energy technology.

Figure 37: Exports of energy technology and equipment from Denmark. Mill. DKK. Source: ENS et al. (2011-2016).



These export figures are based on Eurostat's (Comext database) nomenclature for commodities in an modified version (Dræbye, 2010). For comparison, export figures from the statistics on environmental goods and services mentioned above are for the years 2012-2014 increasing from 39,1 to 44,5 billion DKK/year within renewable energy and from 8,8 to 9,3 billion DKK/year within energy saving and management. Export figures for individual areas of energy technologies are not available from these sources. Therefore, it can be relevant to build analyses on data from the general statistics of industrial trade and commodities.

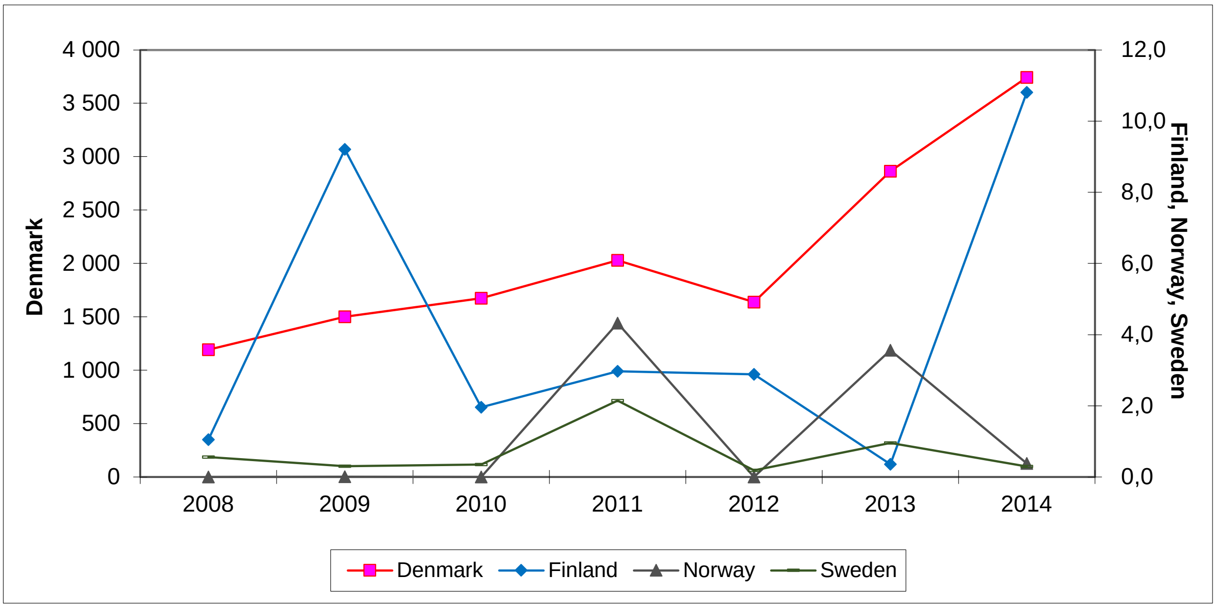
The UN database Comtrade can be used for measuring energy technology exports. However, the list of commodities included in this database does not allow coverage of all energy technologies covered by this report. There are commodities, which address *wind power* (HS 850231) and *hydropower* (HS 841011-13, 841090). For this report, we use just wind power technologies. As has been pointed out by Johnstone and Hascic (2009), *solar photovoltaic* technology may be covered by HS 8541.40, but the commodity group includes not only photovoltaic devices but also light-emitting diodes and semiconductor devices and is therefore far too broad.

Table 14: Wind energy relevant Harmonised Commodity Codes

Chapter 85:	Electrical machinery and equipment and parts thereof; sound recorders and reproducers, television image and sound recorders and reproducers, and parts and accessories of such articles
Heading 8502:	Electric generating sets and rotary converters
HS 850231	Wind-powered generating sets

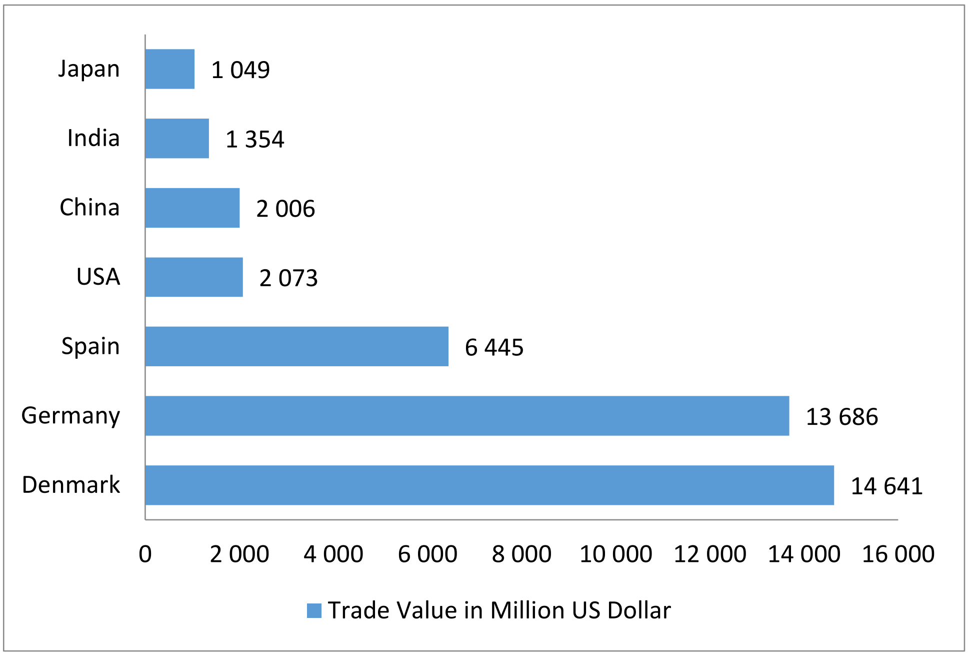
Most of the Nordic export of wind technology comes from Denmark, which is shown in Figure 38. When observing the figure it should be kept in mind that two different axes with different scales have been used; the left one for Denmark and the right one for the other Nordic countries. Export of Danish wind technology has been compared with the rest of the world. Figure 39 illustrates the leading position of Danish wind technology export in a global context, closely followed by Germany.

Figure 38: Wind technology export from the Nordic countries. 2008-2014. Mill. USD.



Source: UN Comtrade Database.

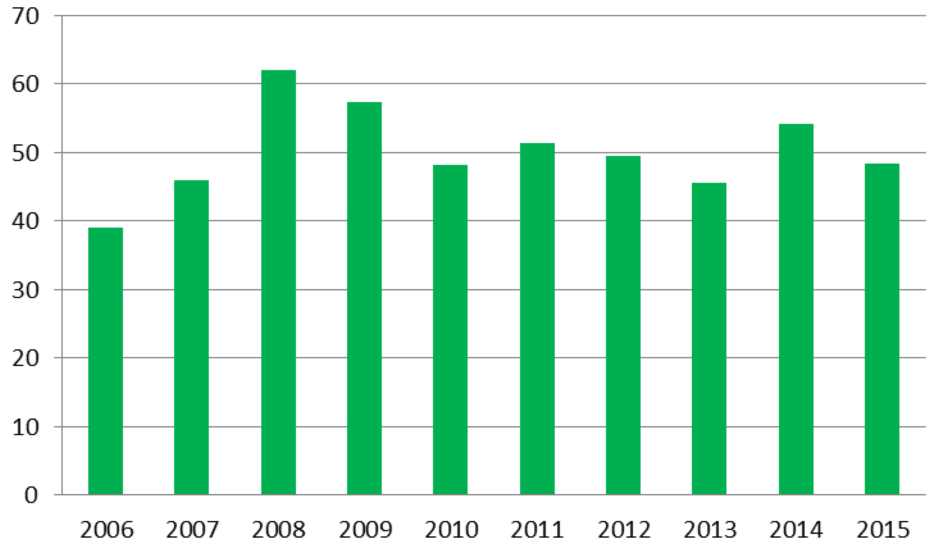
Figure 39: Trade value of exported wind technology. 2008-2014. Mill. USD.



Source: UN Comtrade Database.

It is interesting to notice that the exports figures building on the UN Comtrade database are significantly smaller than the figures from the industry statistics elaborated for the Danish Wind Industry Association, see below. Part of the explanation is that a broader range of services and components, materials, etc. from sub-suppliers are included in the latter.

Figure 40: Wind industry exports from Denmark. Billion DKK. Source: Damvad 2016, based on data from Statistics Denmark.



The exports of energy technology in the recent years constituted more than 10% of the total Danish commodity exports (ENS et al. 2016). Most of the energy technology exports go to Germany and the other North European countries geographically closest to Denmark, see Table 15. Around 11,5 % of the exports go to USA and China.

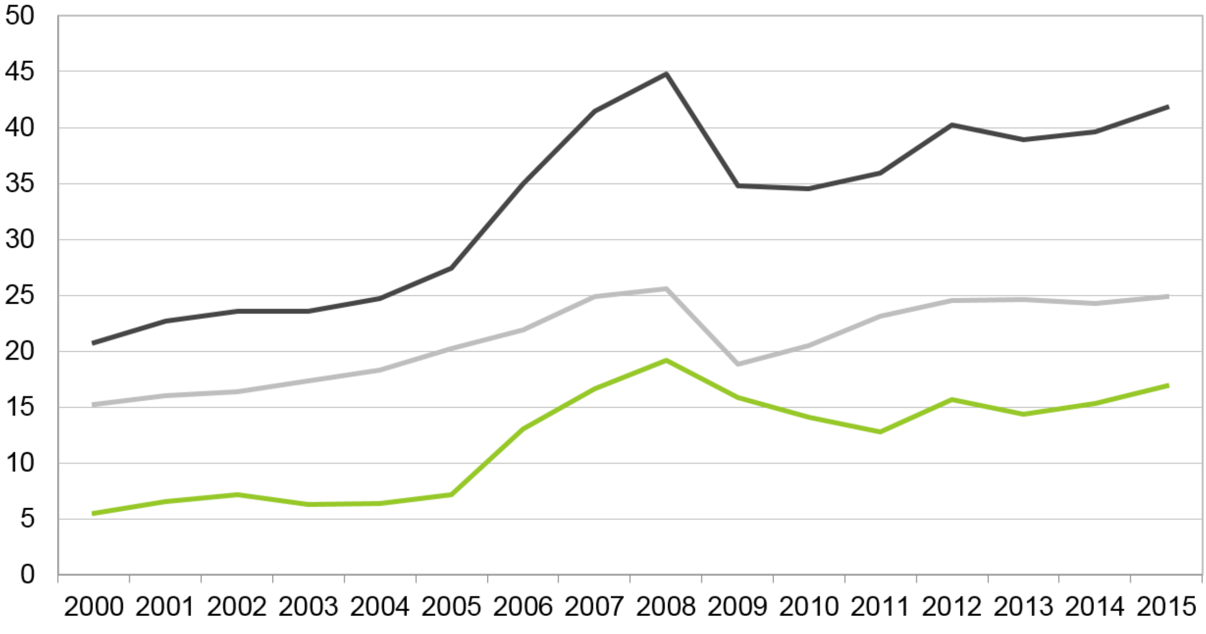
Table 15: Top 10 recipient countries of energy technology exports from Denmark (Billion euro).

No.	2013	2014	2015	Green share	Share
1 Germany	2,0	3,0	3,3	79,73	34,58
2 USA	0,4	0,4	0,7	52,23	7,31
3 GB	1,3	1,1	0,5	65,94	5,56
4 Sweden	0,6	0,7	0,5	45,44	5,36
5 China	0,3	0,4	0,4	27,57	4,21
6 Netherlands	0,2	0,2	0,3	66,82	3,57
7 Norway	0,4	0,4	0,3	20,80	3,43
8 Polen	0,1	0,2	0,3	50,17	2,90
9 France	0,3	0,3	0,2	43,78	2,53
10 Finland	0,1	0,2	0,2	65,95	2,36
	5,65	6,93	6,87	63,87	71,82

Source: ENS et al. 2016. 'Green share' indicates percentage of energy technology exports to the individual recipient country that is green technology. 'Share' indicates percentage of the total Danish energy technology exports.

Earlier, figures on domestic goods supply and domestic market were also published in connection with the export statistics by the Danish Energy Agency and collaboration partners. In addition to offering perspective to the export indicators, these indicators can also be seen as measure of the use- and market-based learning on the domestic market. Updated data for the domestic supply and market has not been available. Figure 41 shows development of imports. Though the imports are smaller than the exports, they are still of a considerable size.

Figure 41: Imports of energy technology and equipment to Denmark. Green technology, other technology, and total, in Billion DKK. Source: DI, building on Eurostat data.

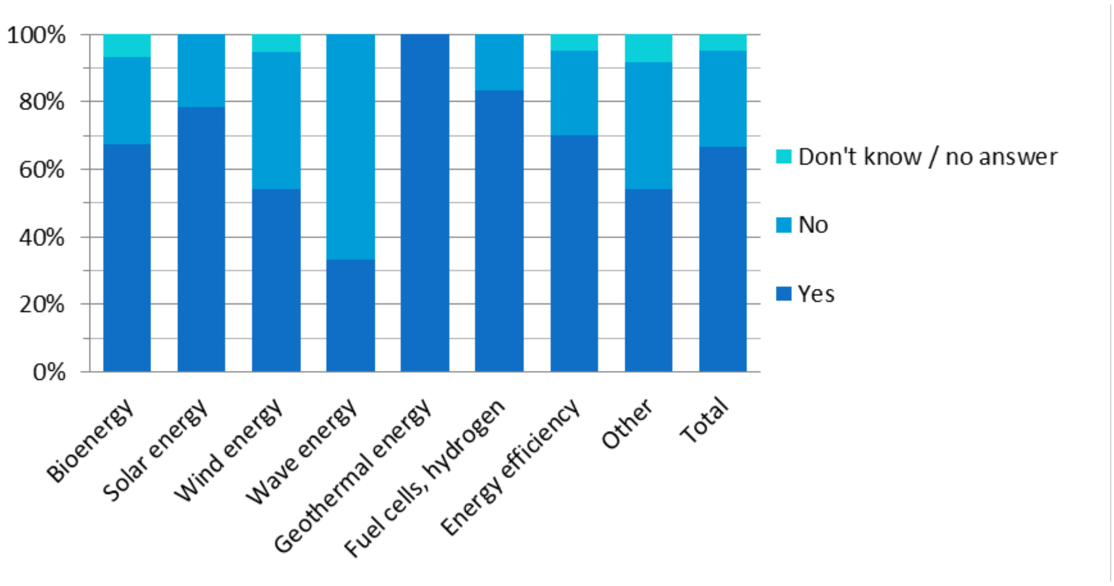


Another indicator that can offer insight in the international competitiveness and technology supply from Danish industry is the share of the world market by the Danish products in individual areas of energy technology. Apart from in economic terms, this can also be measured in energy terms, e.g., share of the globally installed energy effect in a year stemming from Danish technology manufacturers, or share of the total number of new-established energy production plants. Data availability is often a problem here, but in some cases trade literature and reports from international institutions and industry observers make accounts of market shares by different countries or by manufacturers that can be referred to specific countries (see Borup et al., 2008 for examples).

3.3.5 Market introduction of new technological products and services

Another industry- and business-related output indicator of energy innovation systems is the frequency of market introduction of new technological products and services. This is measured e.g. in the EIS surveys (Borup et al., 2013a; 2016). The measuring is made with a method that makes the results comparable with the general innovation statistics by Statistics Denmark and Eurostat (which do not cover the energy area separately). As appear from the Total column in Figure 42, around 63% of the companies in the Danish energy innovation system have introduced new energy technology products or services in the period 2013 to 2015. For comparison the share of innovative enterprises in general in Denmark has in recent years been around 45% (Statistics Denmark 2015, Innovation Statistics).

Figure 42: Introduction of new energy technology products or services. (Share of companies in different technology areas that introduced new products or services in the period 2013-2015.) EIS Survey 2016, N=250.



There is variation between the technology areas, e.g. with a share of 70% or more in the areas of solar energy, geothermal energy, fuel cells/hydrogen, and energy efficiency technology and less than 60% within wind energy, wave energy, and other energy technologies. The results for wave energy, geothermal energy and fuel cells/hydrogen build on a very limited amount of respondents.

3.3.6 Employment

Employment in the energy technology industry can also be seen as an important indicator of the energy innovation system. The employment figures below illuminate the total employment, independently of what the work activities more specifically consist in and whether they have to do with innovation and development activities or not. This is the reason why we here mention them among the output indicators of the energy innovation system. However, if one instead focuses on employees that specifically work with research, innovation and development activities or have an R&D and innovation oriented education, employment figures might also be considered an input indicator. Measuring of such employment figures is in some cases possible from trade and industry statistics, however to our knowledge it has not been done specifically for the energy area.

A recent account of the employment in the energy area in general in Denmark, identifies that the total employment is in the order of 56.000 persons, see Table 16. Of these, around 38.500 work within supply of energy technologies and services and around 2.100 within consultancy. The figure 56.000 corresponds to 1% of the total population and 19% of the employment in industry in general in Denmark (297.400 in 2013; source: Statistics Denmark).

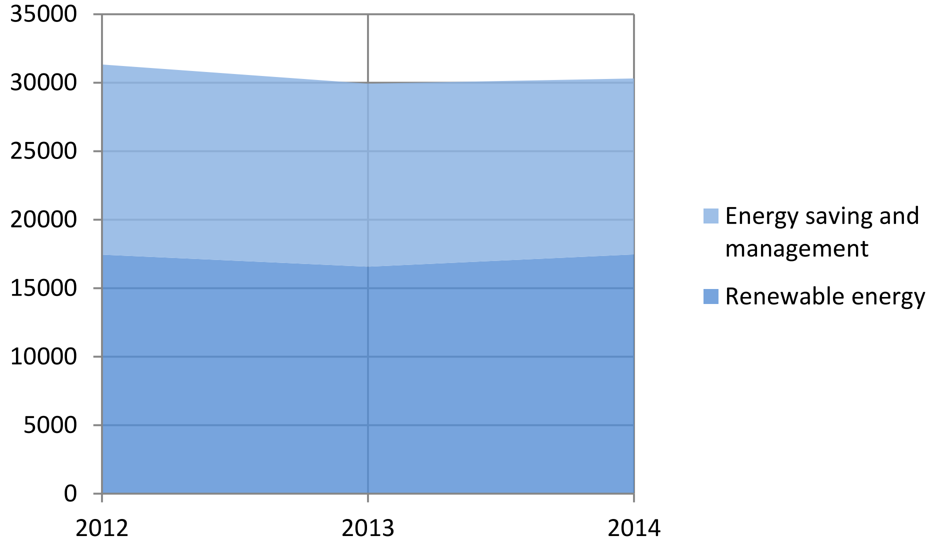
Table 16: Employment in the energy area in Denmark: Number of employed in 2013. Source: Quartz+Co 2015 (building on data from Statistics Denmark, Danish Energy Industry Federation, Danish Association of Consulting Engineers).

Energy sector	15.400
Energy technology and service	38.500
Consultants	2.100
Total	56.000

Figures for development in employment in relation to energy technology, equipment and services in Denmark were earlier available through the statistics on energy technology exports. This is no longer the case. The number of employed varied between 35.000 and 41.000 in the period 2000-2007 (ENS et al., 2011).

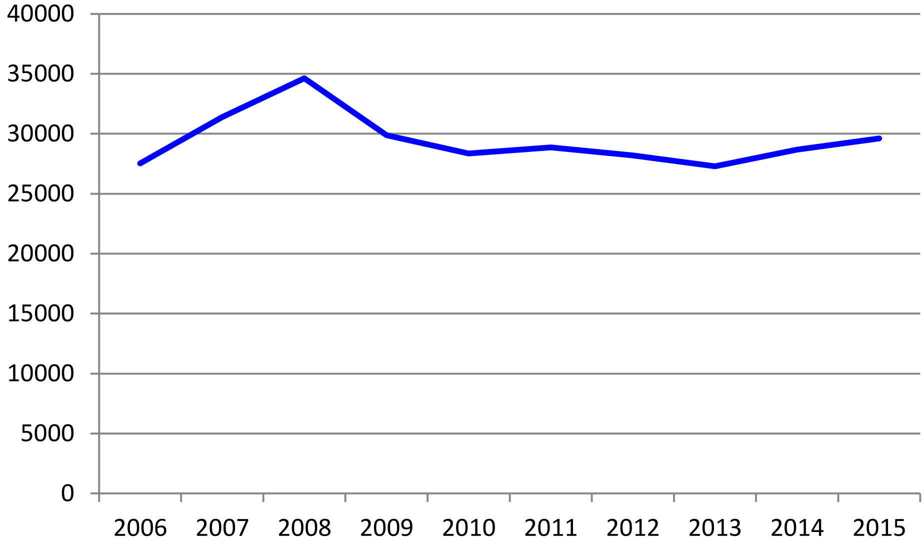
The above figures cover green as well as other energy technology. In recent years, employment figures in relation to goods and services connected to green energy have been available through the statistics on environmental goods and services, see Figure 43. Around 30.000 are employed with green energy goods and services. Well over half of these, around 17.000, appear within goods and services for renewable energy.

Figure 43: Employment in connection to goods and services for production of renewable energy and for energy saving and management. Source: Statistics Denmark, statistics on environmental goods and services.



Analyses made for the Danish Wind Industry Association show a higher number of employees within the wind industry than the above figures connected to renewable energy in general, see Figure 44. After a significant increase in the 00s and a peak on around 35.000 employees in 2008, the employment has in the recent years been between 27.000 and 30.000.

Figure 44: Employment in the wind industry in Denmark. Source: Damvad 2015 and 2016, based on data from Statistics Denmark.



4 Conclusions

Since the publication of the previous version of this report, we have seen some important developments in the official statistics schemes of relevance to energy innovation systems and change towards more sustainable energy systems. The statistics of green goods and services is established and has renewable energy and energy saving and management as two of the major sub-areas. Moreover, the statistics on exports of energy technology and equipment is developed with a distinction between green energy technology and other energy technology. Though the attention to the trade and industry aspects of energy innovation has clearly developed, there is need of further work amongst other things on development of relevant product and technology categories on international as well as national level. On a few points, retrograde steps are seen. Among these are the accounts of the development in the domestic market for energy technology in economic terms. These have not been available in the recent years.

Official and authorized statistics schemes develop slowly. Most of the other developments of indicators of energy innovation systems we have seen in recent years appear from individual research or pilot projects that do not ensure a continued and regular update of data in the years to come. A number of these developments address the interplay in the innovation system (throughput indicators). Among these are indicators of cooperation in the energy innovation systems and accounts of the involvement of different types of actors.

Despite a number of important developments, the general landscape of indicators of energy innovation systems has not fully changed; only a little. The overall picture is still that six of the seven functions for establishment of new energy technologies: knowledge development, knowledge exchange in networks, market formation, mobilization of resources, legitimacy, and entrepreneurial activities are covered to some extent by the available indicators. The seventh function, guidance of the search, is not covered. Of the six covered, knowledge development is the best covered, however also on this function there is room for improvement. The general picture is moreover that there is some information available both concerning the innovative performance and resulting output of the energy innovation system (output indicators), the interplay and activities in the innovation system (throughput indicators) and the supporting platform and investments in it (input indicators). The table below sums up the overall picture.

Thanks to, i.a., the energy statistics and the energy RD&D statistics on national and international level, the energy area is fortunate to have technology-specific data for a number of individual technology areas, including renewable energy forms like solar energy, bioenergy, wind power, etc. This is of central importance for the opportunities for illuminating innovation system dynamics and change processes towards low carbon energy systems. In many other sectors, a similar systematic account of individual technology areas does not exist. We however also see that it is a challenge to maintain a strong technology-specific emphasis in the set of indicators. Firstly, because some of the statistics developing in current years do not distinguish between individual technology areas and make accounts on aggregated level, e.g., on renewable energy as such or green technologies as such. Secondly, because the number of technologies that are considered relevant for change in the energy area has increased. While there earlier was focus primarily on energy production technologies, there is today also attention to energy carriers, conversion, and storage technologies as well as to energy system and control technologies. In addition, an area like the transport area is now to a higher extent than earlier included when considering change processes in the energy sector.

Concerning the broad and heterogeneous area of energy efficient technology, we see some positive developments in the available statistics. Energy efficient technology is included in a number of the recently developed indicator schemes in parallel with indicators of renewable energy technologies, etc. This is for example the case in the statistics on environmental goods and services.

There are numerous interesting developments in the figures for the individual indicators. Which are the most interesting is depending on the perspective and the purpose one shall use it for. To mention two developments that are connected to the data we have ourselves been involved in analysing, we can highlight: the significant and now dominant co-publishing of Danish researchers with Chinese researchers in several fields of energy research; and the significant growth of the solar energy area in Denmark which is reflected in indicators of actors, of RD&D budget as well as of energy production.

Table 17: Coverage of indicators of the different functions in the innovation systems.

	Indicators	**I / T / O**	**Covered?**
Functions:			
Entrepreneurial activities and experimentation	- Experimental application projects - New product introductions - New businesses	T O O-T	Limited (only R&D) Yes No (some e.g. in EIS surveys)
Knowledge development (learning)	- Scientific publications - Technology application (learning-by-using) - R&D funding and projects - Patents	T-I O-T I T	Yes Yes Yes, public (not private) Yes
Knowledge exchange in networks	- Collaboration patterns - Demonstration projects - Network participation - Conferences and debate meetings	T T T T	Yes Some Limited Very limited
Market formation	- Market application - Public market support - Exports - Standards and certifications	O I O T	Yes (energy eff. limited) No. Scattered data Yes, not indiv. technologies No
Mobilization of resources	- R&D funding - Investments - Personnel - R&D / other	I I I / O	Yes, public (not private) Only public R&D programmes Limited
Guidance of the search – shared visions	- Policy action plans - Shared strategies and roadmaps - Debate activities	I I-T T	No No No
Legitimacy	- Public opinions on energy technologies and systems - Regulatory acceptance and integration	I T-I	Yes No

Note: I, T and O indicate input, throughput and output indicators.

Annex

Annex 1: List of acronyms

€	Euro
BERD	Business Expenditures on R&D
CCS	Carbon dioxide Capture and Storage
CIS	Community Innovation Survey, EU
DENP	Danish Energy R&D projects
ECLA	European Classification
EIS	1. European Innovation Scoreboard
	2. Strategic research alliance on Energy Innovation System and their dynamics
ENS	Energistyrelsen
EPO	European Patent Office
ERMINE	Electricity Research Road Map in Europe
ERTD	Energy Research, Technology and Development
EST	Environment Sound Technologies
EU or EU-27	European Union
EW	ERAWATCH
GBAORD	Government Budget Appropriations or Outlays on R&D
GDP	Gross Domestic Product
HRST	Human resources in Science and Technology
HS	Harmonised Commodity Description and Coding System
ICTSD	International Centre on Trade and Sustainable Development
IEA	International Energy Agency
IEADCC	IEA Climate Change Database
IPC	International Patent Classification
IPTS	Institute for Prospective Technological Studies (of the JRC)
ISI WoS	ISI Web of Science
ISIC	International Standard Industrial Classification
JRC	Joint Research Centre (of the European Commission)
MEI	Measuring eco innovations
MS	Member State of the European Union
NACE	Statistical Classification of Economic Activities
OECD	Organisation for Economic Co-operation and Development
PPP	Purchasing Power Parities
PV	Photovoltaic
R&D	Research and Development
RD&D	Research, Development and Demonstration
RCTA	Revealed Comparative Technology Advantage
RON (95)	Research Octane Number (“EuroSuper” or “EuroPremium”)
RTD	Research Technology Development
SET-Plan	(European) Strategic Energy Technology Plan
S&T	Science and Technology
UN	United Nations
UNEP	United Nations Environment Programme
USD	US Dollar
WEC	World Energy Council
2G	Second generation

Annex 2: Unit abbreviations

GJ	Gigajoule
GW	Gigawatt
GWh	Gigawatt hour
kcal	kilocalorie
KJ	kilo joule
kgoe	kilogram of oil equivalent
kW	kilowatt
kWh	Kilowatt hour
Mt	Million tonnes
Mtoe	Million tonnes of oil equivalent
MW	Megawatt
MWh	Megawatt hour
MWe	Megawatt electric
MWth	Megawatt thermal
PPP	Purchasing power parity
Toe	Tone of oil equivalent= 107 kcal
TWh	Terawatt hour

Annex 3: Keywords for bibliometric mapping

2nd generation biofuels

Cellulosic bioethanol
Biomass-to-liquid*
Fischer-Tropsch diesel
Synthetic biodiesel
Synthetic diesel
Bio-methanol
Synthetic natural gas
Lignocellulosic biomass*
Lignocellulosic material*
Gasification synthesis
Anaerobic digestion
Hydrolysis fermentation
Advanced biofuel*
Advanced bioenergy
2nd generation biofuel*
Advanced bioethanol
Bio* pyrolysis

Fuel cells

Fuel cell*
SOFC
AFC
PEFC
PEMFC
Molten carbonate
Nafion membrane*
ZrO2*
YSZ electrolyte

Photovoltaic energy

Solar photovoltaic
Solar AND silicon*
Solar cell*
Silicon* AND wafer
Photoelectrochemical Cell*
Thin film*
Anti-reflection coating
Screen printing

Wind energy

Wind energy
Wind power
Wind turbine*
Wind mill*
Offshore wind*
Onshore wind*
Airborne turbine*
Near-shore turbine*
Wind resource assessment
Wind farm*
Upwind rotor*
Horizontal-axis rotor*
Pitch regulation
Stall regulation
Variable-speed drive
Doubly-fed induction generator
Permanent magnet generator - full converter
Joined blades
Blade winglet*
Slew-ring-type bearings

Annex 4: Patent data and extraction

The results are based on a study with data from the Fall 2015 version of EPO Worldwide Patent Statistical Database (PATSTAT).[5] In particular it utilizes table tls224 on which the categories are based. These categories were first introduced in the 2009 version of Patstat as ‘environmentally sound technologies’. In the subsequent versions of PATSTAT, these technologies have been re-labelled and further refined. See www.cooperativepatentclassification.org for details.

The data covers European patent-applications either via the EPO (application and/or publication authority) or Euro-PCT channels. The unit is the patent-family, according to the earliest filing date.[6] The basis of country of origin is the assignees[7]. The data presentation is based on fractional counting of both the patent applicant and of the technology. This accounts for cases where a single patent-application includes more than one assignee and/or its technology spans more than one category, respectively.

[5] https://www.epo.org/searching-for-patents/business/patstat.html#tab1

[6] Not the application, according to the original filing date, as was the case in the original report.

[7] And not the inventor, as was the case in the original report.

Annex 5: Patent definition of the (sub)fields applied in this report

Field	abbr	subfields	Y-tag ranges used
Solar Energy	SOL	solar thermal energy	"Y02E10/40" through "Y02E10/49"
		photovoltaic energy	"Y02E10/50" through "Y02E10/59"
		hybrid energy	"Y02E10/60" through "Y02E10/69"
Wind power	WIN	wind energy	"Y02E10/70" through "Y02E10/79"
Bio energy	BIO	biofuels	"Y02E50/10" through "Y02E50/19"
		fuel fom waste	"Y02E50/30" through "Y02E50/39"
Hydro power	HYD	hydro energy	"Y02E10/20" through "Y02E10/39"
Combustion technologies with mitigation	MIT	combustion technologies including CCS	"Y02E20/00" through "Y02E20/19"

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